TIEMEC
1995

THE INTERNATIONAL EMERGENCY MANAGEMENT AND ENGINEERING CONFERENCE 1995

Globalization of Emergency Management and Engineering:

National and International Issues Concerning Research and Applications

May 9-12, 1995
Nice, France

THE NATIONAL INSTITUTE FOR URBAN SEARCH AND RESCUE

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James D. Sullivan • Jean Luc Wybo • Laurent Buisson

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Edited by
James D. Sullivan
Optimal Systems, Inc.

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Laurent Buisson
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Conference Sponsor
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and
National Institute for Urban Search and Rescue
[NI/USR]

With the personal patronage of
Mr. Antonio Ruberti, Member of the European Commission
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Preface

Even as you read this, there may be someone suffering and dying as a result of an emergency somewhere in the world. Emergencies of all types are common enemies of us all. The international Emergency Management and Engineering Society (TIEMES) is dedicated to bringing together the research, development, and application communities from all disciplines to improve our abilities to cope with emergencies. We focus on advance technology from both a managerial and a scientific viewpoint; thus our interests include computers and communication systems as well as the social science and management aspects involved in emergency management and engineering.

We began as a special interest group of a larger computer society in 1982, and conferences were held in 1983, 1985, 1987, 1989, 1991, 1992 and 1993. During the 1993 conference, we decided to become an independent organization, and our "first" conference (as an independent nonprofit professional society) was held in Miami (Hollywood Beach), Florida, in 1994. All of our conferences prior to this year have been in the United Stated. As a result, we become truly international with the 1995 conference.

During the 1980s, our growth was slow. However, interest in mitigating, preparing for, responding to, and recovering from both natural and technological disasters has grown considerably during the 1990s; and TIEMES has grown rapidly as well since 1991. As we have grown, our interests have expanded. We realize that it will take everyone working together to solve the problems created by emergencies.

Despite the fact that this is our first trip to Europe, we have developed a tremendous program, as evidenced by this proceedings. There are over 90 papers in this volume from all over the world, more than we have ever had in any past conference. I believe the overall quality of papers has improved as well. So I feel safe in saying that this proceedings once again has set the standard for the state-of-the-art and pushed the frontiers forward in the field of emergency management and engineering.

And this success is the result of the hard work and dedication of many individuals who worked together to organize this conference. I would like to thank the TIEMES Executive Committee and the TIEMEC 1995 Steering Committee for contributing to the success of the 1995 conference.

Several individuals deserve special recognition. Jean Luc Wybo has performed an outstanding job as Program and Local Arrangements Chair. Laurent Buisson has served as Associate Program Chair, and done a superb job in that capacity. Verner Andersen has distinguished himself by recruiting a large number of quality papers and by assisting in many other ways. Sandro Bologna has performed admirably, as well. Walther Hays has also helped in many important ways. Bob Crowley has provided some invaluable assistance when I needed it the most. Thanks also go to Kathleen Kowalski, Saye Atkinson, Jim Smith, and David Bakuli for helping out with special projects. And perhaps I feel the most gratitude to Don Newsom whose help went far beyond the call of duty.

I would also like to thank Giampiero Beroggi for securing the "in cooperation status" from EURO, Suleyman Tufekci for obtaining the approval for cooperation status from both INFORMS (formerly ORSA/TIMS) and IIE, and Lois Clark McCoy for approving cooperation status for the NI/USR.

Jean Luc Wybo persuaded École des Mines de Paris to welcome the conference to their facilities on the French Riviera, and Laurent Buisson persuaded CEMAGREF to serve as a cosponsor. Jean Luc also convinced Mr. Antonio Ruberti, Member of the EC, to approve cooperation status from the CEC. Mr. Antonio Ruberti gives his personal patronage for the conference, and we are very grateful to him.

We deeply appreciate École des Mines de Paris, CEMAGREF, the CEC, EURO, IIE, INFORMS, and NI/USR for their support for our efforts. It is a strong indication that we continue to move in the right direction.

"Last but not least", I would like to thank Dave Braxton for all his hard work and patience in preparing this proceedings for publication.

Without the authors, of course, we would not have a conference. Because of the outstanding contributions they have made and reported in their papers, we have been able to produce a high-quality proceedings selected from the submissions to TIEMEC 1995.

This volume is organized into several major sections, each with several subsections. Each subsection contains several related papers. The major sections are: Management and Social Sciences; Training; Natural Disasters; Nuclear Hazards; Chemical Hazards; Research; and Applications. There is also an Appendix which contains a paper related to emergency management and engineering.

This volume is dedicated to a small but growing group of good people who reside on an insignificant pile of dust which floats through the infinite universe, and who cared enough about their fellow human beings to spend a good portion of their short time on earth making this world a better place to live.

CARPE DIEM!

James D. Sullivan
General Chair

Préface

L'association internationale pour la gestion et l'ingénierie des catastrophes (TIEMES en anglais) est dédiée à rassembler les communautés de chercheurs de développeurs et d'utilisateurs provenant de toutes les disciplines pour améliorer notre aptitude à gérer les catastrophes. Nous mettons l'accent sur les technologies avancées, sous l'angle de la science et de la gestion. Ainsi, nos centres d'intérêt incluent l'informatique, les télécommunications mais également les sciences sociales qui participent à la gestion et l'ingénierie des catastrophes.

Nous avons débuté notre activité en 1992 comme groupe d'intérêt d'une association plus importante dédiée à l'informatique, et des conférences ont été organisées en 1983, 85, 87, 89, 91, 92 et 93. Lors de la conférence de 1993, nous avons décidé de devenir une organisation indépendante, et notre première conférence (en tant qu'association indépendante à but non lucratif) s'est tenue en 1994 à Miami (Hollywood Beach). Toutes nos conférences, jusqu'à aujourd'hui, ont eu lieu aux États Unis et notre association ne devient réellement internationale qu'avec celle de 1995.

Durant les années 80, notre croissance a été lente. Cependant, l'intérêt pour la préparation, la réponse, l'atténuation et la récupération des catastrophes naturelles et technologiques a cru considérablement dans les années 90. De même, l'association TIEMES a cru rapidement depuis 1991. En grandissant, nos centres d'intérêt se sont diversifiés, et il est apparu évident que nous devions tous travailler ensemble pour résoudre les problèmes posés par les catastrophes.

En dépit du fait que ce soit notre premier déplacement en Europe, nous avons établi un programme étendu, comme on peut le constater à la lecture de ces actes. Il y a plus de 90 communications provenant de toutes les régions du monde, soit plus que nous n'en avons jamais rassemblé dans les éditions précédentes. Je pense que la qualité des présentations a également progressé. Aussi, je peux dire que ces actes, une fois de plus, constituent un état de l'art et contribuent à repousser les limites de la gestion des urgences.

Ce succès est le résultat d'un important travail et du dévouement de nombreux individus qui ont collaboré pour organiser cette conférence. J'aimerais le comité exécutif de TIEMES et le comité d'organisation de TIEMEC '95 pour avoir contribué au succès de cette conférence.

Je dois également remercier certaines personnes. Jean Luc Wybo a . Laurent Buisson a également largement contribué au comité de programme. Verner Andersen s'est distingué en recrutant un grand nombre de présentations de qualité et sur de nombreux autres plans. Sandro Bologna a également contribué largement, ainsi que Walter Hays. Bob Crowley a fourni une assistance inestimable lorsque j'en ai eu le plus besoin. Merci aussi à Kathleen Kowalski, Saye Atkinson, Jim Smith et David Bakuli pour leur aide dans différents domaines. Et j'ai peut-être le plus de gratitude pour Don Newson qui m'a aidé bien au delà de ma demande.

Je voudrais aussi remercier Laurent Buisson d'avoir convaincu le CEMAGREF de nous parrainer, Giampiero Beroggi pour avoir obtenu la coopération d'EURO, Suleyman Tufekci pour celles d'INFORMS (ORSA/TIMS) et d'IIE, enfin Lois Mac Coy pour avoir approuvé la coopération de NI/USR.

Nous apprécions beaucoup le support de ces institutions, car cela constitue pour nous une reconnaissance que notre association est sur la bonne voie.

Je remercie particulièrement Jean Luc Wybo pour son action dans le comité de programme et l'organisation locale, pour avoir persuadé l'École des Mines de Paris d'accueillir notre conférence dans ses locaux de Sophia Antipolis et pour avoir convaincu Monsieur Antonio Ruberti, Commissaire Européen, de nous apporter son patronage personnel, ce dont nous le remercions chaleureusement.

Enfin, et ce n'est pas le moindre, je voudrais remercier Dave Braxton pour son travail et sa patience lors de la préparation de ces actes.

Sans les auteurs, bien sûr, nous n'aurions pas de conférence ! A partir d'une sélection des contributions proposées a TIEMEC '95, nous avons pu réaliser grâce à eux des actes de grande qualité.

Ce volume est organisé en plusieurs sections principales, divisées en sous-sections, chacune regroupant plusieurs papiers apparentés. Les principales sections sont consacrées à : Gestion et sciences sociales, Formation, Catastrophes naturelles, Risques nucléaires, Risques chimiques, Recherche et applications.

Ce volumes est dédié à un petit groupe de personnes qui vit sur un îlot de poussière flottant au milieu de l'univers et qui a décidé de passer une bonne part de son temps à essayer de rendre ce monde plus agréable à vivre pour leurs semblables.

CARPE DIEM!

James D. Sullivan
General Chair

Introduction

Emergency Management has been a continuing preoccupation throughout human history. Society is periodically faced with disasters which, except for wars, are usually created by nature.

In ancient times, people were primarily motivated to protect their own lives by avoiding regions of known risks and thus escaping from disasters. As civilization has developed and cites have grown, some general emergency management strategies have evolved, such as dams for protection against floods.

In recent years, the demand for energy and industrial products, the increasing population density in urban areas, and the development of tourism has expanded the range of potential disasters. A typical characteristic of this period, beginning approximately with the 20th century, is a common feeling that the power of mankind has almost no limits and that technology is able to solve all problems, including those related to Emergency Management.

Some recent disasters (oil spills from tankers, nuclear plant accidents, chemical disasters, floods, and hurricanes) have demonstrated the limits of our power over natural and technological disasters. However, we are hopeful that engineering and the social sciences will continue to progress and that some aspects of technology, such as computers and telecommunications, will provide more efficient strategies for Emergency Management.

What science may provide will be of limited value if mankind does not participate in this challenge. Growing concern for the environment, increased awareness of risk, and the desire for a happier life, motivate us to be optimistic for the future, even in the face of present poverty, unemployment, wars, and increasing world population.

TIEMES is a young Society whose creation corresponds to the need for unification and cooperation on a worldwide scale. Since the first conference in Miami, collaborations have been launched between the individuals and groups involved in Emergency Management, cutting across disciplines and national borders to unite efforts. The quality and quantity of the communications reproduced herein from the proceedings of our second international conference demonstrates the ongoing commitment to share knowledge in the important area of Emergency Management. We hope the result of this conference will be increased and enhanced collaboration. Global participation is essential so that we may face the worst of disasters with the best of our efforts.

In 1783, six years before the French Revolution, École des Mines de Paris was founded. The purpose was to provide France with high-caliber engineers, capable of solving the problems and challenges arising from the development of energy and natural resources at the very beginning of the industrial era.

Since that time, our students have contributed to major advances in technology and to the principal industrial pursuits around the world.

Currently, the mining industry is not as critical as it once was. As a result, our curriculum has been expanded to meet the needs and concerns of society.

Today, the major engineering activities of École des Mines de Paris are: material science, energy, informatics, applied mathematics, economics and the social sciences. Our professors and research scientists contribute to Emergency Management in the fields of industry, environment and decision support.

As an old representative of the European Academic Community, we are pleased to welcome the annual conference of this new and promising Society: TIEMES.

Jean Luc Wybo
École des Mines de Paris

Introduction

La gestion des catastrophes est une préoccupation constante dans l'histoire de l'homme. La société a été périodiquement confrontée à des désastres qui ont été, à l'exception des guerres, principalement d'origine naturelle.

Dans les périodes anciennes, les hommes cherchaient à sauver leurs vies en se protégeant individuellement et en évitant les zones dangereuses. Avec le développement de la civilisation et la croissance continue des villes, des stratégies collectives sont apparues, comme la création de digues pour éviter les inondations.

Dans les périodes récentes, la demande d'énergie et de biens de consommation, l'accroissement de la densité de population dans les zones urbaines et le développement du tourisme ont accru le nombre et la diversité des catastrophes potentielles. Une caractéristique spécifique de cette époque, qui commence approximativement au début du vingtième siècle, est le sentiment largement partagé que la puissance de l'homme n'a pratiquement pas de limites et que la technologie est capable de résoudre tous les problèmes, notamment la gestion des catastrophes.

Des désastres récents (marées noires, accidents dans des centrales nucléaires ou des complexes chimiques, inondations, tornades, . .) ont démontré les limites de notre puissance sur la maîtrise des catastrophes naturelles et technologiques. Au delà de ce constat, l'ingénierie et les sciences sociales continuent à progresser et certains aspects de la technologie, comme l'informatique ou les télécommunications amènent des améliorations significatives dans les stratégies de gestion des catastrophes.

Ce que la science peut apporter serait de faible portée si l'homme ne participait pas aux enjeux. La prise en compte croissante de l'environnement, une meilleure perception des risques et le désir d'une vie plus heureuse nous rendent optimistes pour le futur, même si la pauvreté, le chômage, les guerres et l'accroissement de la population mondiale tempèrent cet optimisme.

TIEMES est une jeune association dont la création correspond à un besoin d'unification et de collaboration à l'échelle mondiale. Depuis la première conférence à Miami, des collaborations ont été établies entre les frontières. La qualité et la quantité des communications présentées cette année dans le cadre de cette deuxième édition démontrent la volonté croissante de partager les connaissances dans le domaine de la gestion des catastrophes.

Nous espérons que le résultat de cette conférence sera l'établissement d'une collaboration encore plus étroite entre les participants et contribuera à l'effort commun indispensable pour affronter les catastrophes à venir dans les meilleures conditions.

L'École des Mines de Paris a été créée en 1783, six ans avant la révolution française. Sa vocation première est de fournir à la France des ingénieurs de haut niveau, capables de résoudre les problèmes et les enjeux associés à l'énergie et aux matières premières, dès les premiers temps de l'ère industrielle. Depuis lors, nos ingénieurs ont contribué aux progrès de la technologie et aux principales conquêtes industrielles dans le monde.

Aujourd'hui, l'industrie minière n'est plus aussi importante et la formation des ingénieurs a évolué pour s'adapter aux besoins de la société. Actuellement, les principaux domaines enseignés à l'École des Mines de Paris sont les matériaux, l'énergie, l'informatique, les mathématiques appliquées, l'économie et les sciences sociales. Nos enseignants et nos chercheurs participent à la gestion des catastrophes dans les domaines des processus industriels, de l'environnement et de l'aide à la décision.

En tant que représentant de la communauté académique européenne, nous avons le plaisir d'accueillir dans nos locaux la conférence annuelle de cette jeune et prometteuse association: TIEMES.

Jean Luc Wybo
École des Mines de Paris

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MANAGEMENT AND SOCIAL SCIENCES

TIEMEC '95

Policy Issues in Emergency Management

Chair:
James D. Sullivan
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UNCERTAINTIES IN RISK TOLERABILITY

Keith Cassidy
Head of Major Hazards Assessment Unit
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ABSTRACT

The management of risk is now recognised as central to the effective and efficient operation of industry and commerce and is widely practised. Risk Management has economic, political and human dimensions, which in all cases involve pivotal judgements relating to the acceptability or (as appropriate) tolerability of the criteria which underpin the executive decisions and actions in the risk management process. How robust are the techniques used to arrive at such judgements? And how can existing variations in tolerability criteria be explained or justified? The developing methodologies contain many uncertainties (for example, selection of failure cases from a range of possibilities; failure possibilities in each case; scale of modelling and consequence uncertainties; model validation; parameter values of the models used; uncertainties in enhancing and mitigating factors). How far do these uncertainties affect the validity of risk management decisions? And how sensitive are these decisions to aspects of uncertainty? How far do the influences affecting public perception of the type, nature and magnitude of any risks affect the nature of risk management? (for example, issues such as voluntary vs involuntary exposure; natural vs man-made risks, perceptions of personal control, familiarity, perceptions of benefit or disbenefit, the nature of the hazard, the nature of the threat, the special vulnerability of 'sensitive' groups, public perceptions of comparators, reversibility of effects, all may be felt to influence significantly the decision making process). Expression and communication of risk (particularly methods of calculating and expressing societal risk) may compound any problems.

RISK MANAGEMENT

Not surprisingly, there is no agreed definition of 'risk management' - the issues involved may be very complex - but it is possible to characterise the overall process into a coherent overall architecture, based on the principles of

- IDENTIFICATION -the recognition and location of any potential problem;
- ASSESSMENT - the bounding and dimensioning of any potential problem;
- CONTROL - the limiting of the scale of any potential problem, by prevention or avoidance;
- MITIGATION - the amelioration of the residual elements of the potential problem.

This is a strategy first applied, in the UK, to the control of major chemical hazards as a result of the recommendations of the UK Advisory Committee on Major Hazards but it is an overall approach which is universally applicable. Measures used to parameterize, or to limit, the component elements may vary between hazards and risks, between different components of the overall environment, or between different economic and cultural systems; but the underpinning logic of the approach remains as a taxonomy comprising overall environment, or between different economic and cultural systems (1). At the core of a risk management approach lies a simple question set. Essentially the core questions are:

WHAT IF? WHAT THEN? THEN WHAT? SO WHAT?

'What if?' requires a combination of technical expertise, experience, and a degree of imaginative insight. 'What then?' and 'Then what?' are essentially the techniques and practices of risk assessment. 'So what?' is the area of judgement, informed but not constrained by the earlier inputs. It is a decision process, often rigorous, which involves:-

a) dimensioning of likely risk with an understanding of the inherent uncertainties involved in the assessment process (answering the question 'How much of what kind of what risk of what to whom or what?)
b) reference to the likely benefits generated and the political and economic considerations associated with it
c) judgements as to tolerability or acceptability for groups directly or indirectly affected; and
d) sometimes, decisions as to further reductions in risk taking cost (including effort, and available technology) into account.

It is, in short, a process which is essentially economic and political, technically informed.

THE ROLE OF QUANTIFIED RISK ASSESSMENT (QRA) IN THE RISK ASSESSMENT AND THE DECISION MAKING PROCESSES

Quantitative risk assessment (QRA) continues to be at an infant stage of development, plagued by problems of recognition, precision, and credibility (2). A UK Royal Society report (3) laments the deep methodological division regarding such issues as the quantification and qualification of risks, the response of QRA to public perceptions of risk, and the setting of acceptable standards for decision making. According to Blockley (4), this division points to the "open-world" nature of risk problems, which Fischhoff (5) ascribes to differences in human interpretation and judgement, an inherent attribute of QRA applications in general.

QRA applications in most areas of risk are plagued by a number of practical concerns that compromise their usefulness in decision making. Hubert and Pages (6) and Saccomanno et al (7) cite a number of inconsistencies in the values assigned by different groups to various components of risk for similar problems. These inconsistencies, it is argued, have contributed to a general loss of credibility in QRA's ability to provide accurate readings of the threats posed. A 1989 Health and Safety Executive (HSE) report (8) argues that the views held by members of the public are often at variance with apparent evidence from QRA applications. Covello (9) has noted that the reasons for this cannot be dismissed as purely "irrational" or "subjective" thinking by the public concerning risk assessment in general, but rather it rests with the ability of QRA to "communicate risk" in an effective and consistent manner. Glickman et al (10) suggests that there is a wider concern that, notwithstanding the question of inconsistencies in the estimates, existing QRA models have failed to express risk in a manner that is responsive to the specific needs of users and decision makers. They argue that QRA should be made more practicable and not necessarily more technically involved. Before proceeding further along the path to "bigger and better models", a momentary halt in progress is advisable to take stock of our current position on the learning curve and map out future directions for QRA model development. Indeed, there may be many different types of learning curve to consider in risk assessment.

There are however, some generally accepted tenets:-

1. QRA must be more responsive to the needs of users and decision makers.

Both information requirements and output must be clearly defined and documented.

2. Uncertainty must be fully accounted for in the reporting of risk estimates. Risk and its components must be accompanied by confidence limits. The sensitivity of output to various assumptions concerning parameter values and inputs must be accounted for in the reporting of the risks.

3. Risk measures must be clearly defined. There should be no ambiguity concerning the nature of risks and their perspective, such as individual and societal, or absolute and relative risks. Risk communication guidelines need to be developed before the analysis begins.

4. Guidelines for decisions and the mitigation of risk must be incorporated into the QRA models. The process must lead to technically informed decisions. Where appropriate, QRA should present output in a form that can be readily used in a cost-benefit evaluation of alternative types of mitigation.

In this context QRA has three important roles to play:-

1. Provide acceptable and credible estimates of risks;
2. Inform public perception of the nature and importance of these risks; and interpret the technical results; and
3. Provide advice on mitigation in support of the decision-making process.

The provision of acceptable and credible risk estimates is an attempt to reduce uncertainty in risk estimation, recognising that, given the nature of QRA, uncertainty can never be fully eliminated. The questions to be addressed are: to whom should these estimates be acceptable and credible? and how is this to be achieved in QRA? A major U.S. National Research Council report (11) addressed part of this issue by noting that QRA can be "successful to the extent that it raises the level of understanding of relevant issues or actions and satisfies those involved that they are adequately informed within the limits of available knowledge".

The second role of QRA is to communicate risk effectively; that is, to report and interpret the technical results so as to bridge the information gap between the technical analyst and the decision maker or user (who may or may not be a technical person). One critical issue is whether existing QRA models suitably "inform" public perceptions on the actual threats posed by a given activity. Some commentators believe that at present QRA models have not contributed adequately to a complete understanding of the risks involved, so that well-informed decisions have not always been possible. This issue has been echoed widely in the literature. The 1983 Royal Society report on risk assessment noted (12):

If follows that the public not infrequently have different perceptions of events from those suggested by the objective statistical assessments made by scientists or *other experts (here referred to as QRA). Since policy is rightly directed towards the alleviation of public anxieties, this disparity can lead to large expenditures on safety measures that have low cost-effectiveness or, conversely, to the neglect of serious risks because the public (and by extension the decision makers) happen to be relatively indifferent towards them.*

The absence of communication among those involved in QRA development has contributed to much of the misunderstanding on QRA's role and how well existing models fulfil this role. Closely related to the issue of risk communication is the role of QRA in decision support (i.e. as a guide to evaluating alternative risk-mitigation strategies). In this regard, risks should be reported in a manner that suggests an appropriate course of action for specific problems. The role of QRA will be discussed in this paper from these three points of view; namely, risk uncertainty, communication, and decision support for mitigation.

RISK UNCERTAINTY

The nature and degree of uncertainty in QRA varies with the nature of the problem being addressed and how the relevant issues are perceived by the analyst. Uncertainty in the quantification of risk can take several forms:

1. "Measurement error" expressed in the formal scientific sense as the range within which a parameter is known to lie with a given level of confidence;
2. Uncertainty in the modelling process;
3. Uncertainty in whether or not there is indeed an effect to be incorporated in an estimate; and
4. Omissions of possible causes of risk because of incomplete analysis, non quantification of the ways in which human error can arise, and omission of other extreme external causes.

In many existing QRA models, uncertainty is handled in one of four ways:

1. *Use of the so-called "best estimate" approach for all input components of risk.* Frequently, the best estimate is obtained from sample averages extracted from the literature or from observed data;
2. *Erring on the side of safety.* Estimates are made considering the so-called worst-case scenario for each component of risk. The argument is made that even if the final risk estimate is incorrect, the assessment would not compromise safety. (Some may use a "cautious best estimate" approach, which is essentially a combination of the first two of these methods;)
3. *Sensitivity analysis to varying inputs.* If risk component values are uncertain, a range of possible input values is obtained for each component and the implications on the final risk estimates are assessed; and
4. *Comprehensive statistical analysis of risk inputs and outputs.*

There are, of course, serious limitations in several of these ways of handling risk uncertainty in the application of QRA. Rimington (13A) and Haigh (13B) argue that the use of the most likely estimate or erring on the safe side alone is simply not acceptable, given the high cost of the decisions involved. Sensitivity analysis addresses how a range of values in selected inputs can affect risk estimates, without addressing specifically the reliability of these estimates. As such, the uncertainty issue is not fully addressed in this approach. Another use of sensitivity analysis is to determine whether the changes in the value of inputs make any difference to the resultant outputs. If the output is insensitive to the selected input values, the question is: why worry about the reliability of these input values? Of the previously listed methods for dealing with uncertainty, a comprehensive statistical review of risk and its inputs appears to be the most desirable course of action to take, although the amount of information required to carry out this type of analysis may not always be adequate.

In adopting a statistical approach, Saccomanno and Bakir (14) note that two types of uncertainty need to be considered: (a) uncertainty in risk estimation and (b) uncertainty in the process. The first type of uncertainty is an "uncertainty of knowledge" concerned with the value of the inputs and their parameters. The second type treats risk as a random variable, with a range of possible values tending about the mean. As in any random variable, the values assigned to risk and its inputs can be represented by their unique probability density functions.

RISK ESTIMATION: SOME AVAILABLE TOOLS

Very considerable international effort has been deployed on the development of methodologies and models (the 'tools') for risk assessment and estimation. In the field of major chemical hazards, the common components are

- in identification: the use of a substance/threshold approach (and the importance of the search for a hazard or risk equivalence system);
- in assessment: the classical approaches to consequence and probabilistic assessment. These include Comparative methods, such as Process/system checklists, Safety Audit Review, Relative Ranking (eg Dow and Mond Indices), Preliminary Hazard Analysis;

Fundamental Methods such as Hazard and Operability Studies, 'What if?' Analysis, Failure Mode and Effect

Analysis, Failure Mode, Effect, and Criticality Analysis, Goal Oriented Failure Analysis; and

Logic Diagram Methods, Fault Tree Analysis, Event Tree Analysis, Cause Consequence Analysis, Human Reliability Analysis, System Success Trees.

- in control: the application and enforcement of technical, operational and legal standards; information and descriptive packages (eg the 'safety report' approach); descriptive and analytical system justifications (the 'safety case' approach); licensing approvals or other ways of granting permission.
- in mitigation: on site emergency planning; off site emergency planning; information to those who may be affected by the risks; controls over incompatible land use; siting controls for risk sources. It is an approach which (in for example the context of major chemical risks)

(a) identifies the nature and scale of use of dangerous substances;

(b) places the use in its geographical and social context;

(c) identified the type, consequence and relative likelihood of potential harm;

(d) identifies the control regime and systems (both hardware and peopleware) to obviate that potential for harm;

(e) justifies the adequacy of the level of control (in the context of any tolerability criteria) (15) and demonstrates the broadly acceptable levels of any residual risk (again in the context of tolerability criteria).

Again however, there are many uncertainties in all aspects of the above, which bear directly on risk management decisions. These, even at the basic level, include (16)

the selection of failure cases from the range of possibilities

failure probabilities for each failure case

scale of release rates and duration

conversion of a failure case to a source term for use in further calculation

the validity of the dispersion model
    meteorological inputs
    topographical inputs
    human and environmental response to toxic,
pressure or thermal burdens
    ameliorating factors
    ignition factors
    and in particular
    parameter values in many of the mathematical models.

Of course, there are techniques to compensate for such uncertainties. Much effort is being expended on 'fuzzy logic' approaches; sensitivity testing, always an essential tool, is very useful here. But the criticality of such approaches demonstrates the vulnerability and impression of the models used, and the further sensitivities of risk management decisions taken on the basis of QRA outputs.

THE ROLE OF RISK MEASUREMENT IN THE COMMUNICATION OF RISK

A major role of (Q)RA is the effective communication of the risks involved. Covello (12 Ref ante) identified 19 characteristics of Tisk which must be considered in QRA applications if there is to be sufficient information for evaluating these risks and making appropriate decisions. These characteristics can be grouped under three major headings

- perspective on risk, which refers to ways in which risks are viewed by users and decision makers within the context of the problem being addressed
- Criteria for measuring risk, which refers to analytical output from QRA
- relevance to decision making, which addresses the broader issue of the ability of QRA to advise on an appropriate course of action.

Most QRA models express individual risk as the probability of a stated detriment (often death) per unit interval of time, often in terms of equal probability isopleths, etc. Societal risks are, however, more complex, being normally expressed either as an expectation of harm (often death) or as a plot of the frequency of N or more deaths per unit time versus the number of deaths. This latter more complete representation of societal risk is the cumulative F-N curve. Societal risk expectation is simply the expected value of the F-N curve.

There appears to be some consensus that FN curves, despite their complexities, uncertainties, and difficulties, currently offer the best means of expressing societal risk. However, various commentators have suggested ways in which the curves can be better represented. These include

a) the use of probability density functions and probability of exceedance curves (Bernouilli, exponential, and inverse quadratic), in which Vrijling et al (17) merge two specific Dutch approaches into a simple theory of acceptability,

b) extending the range of consequences reflected in the F-N relationship, to include other consequence measures - especially as these may affect different mitigating responses. The measures could include personal injury, property damage, environmental impact, and relate to both short term and long term harm.

c) using alternative ways of defining risk consequences. Here the probability of incurring fatality in the F-N curve requires an additional step in the analysis to translate 'exposure to dose' to 'fatality response', normally using a probit dose-response formulation, in which the input dose (expressed as a function of concentration and exposure time) becomes an input to a probit expression, with the dependent variable being a measure of the probability of death.

d) linking F-N curves to mitigation. This can include mitigation measures at both the individual level and at the level of official or other response

e) including monetary factors. In real terms, decisions are rarely made in the absence of financial considerations (ie. the cost of mitigation vs the benefits of risk reduction). This approach requires the risk output to be reported in such a way as to permit a thorough cost effective valuation of alternative forms of mitigation. It could involve assigning values to deaths, injuries and property values in the F-N curves and assessing the costs of alternative types of mitigation, including emergency response (inc. evacuation), containment, and clean-up, as well as risk avoidance. Some current research work by Keller & Cassidy (18) is providing useful insights into the potential of this approach, converting accident and other data to logarithmic magnitudes and analysing using Maximum Likelihood, with exponential Weibull, and a specialised Weibull, probability distribution analysis.

f) expressing uncertainty in the F-N relationship. Because uncertainty in risk estimation varies with the number of reported cases used in validating the model estimates, the uncertainty associated (for example) with very low frequency/high consequence events is likely to be greater than the uncertainties in the reverse case. Accordingly, certain regions of the F-N curve are more prone to uncertainty than other regions, and this should be taken into account in representing the results. The normal procedure for this is to establish confidence limits about each point on the F-N curve. Of course, imperfect information will always produce risk estimates that are subject to error. True values of risk are unlikely ever to be known. Confidence bands in F-N curves are helpful to decision makers because they provide a range of values within which the true value of risk lies, with a percentage level of confidence. The bands can also serve as a basis for comparing uncertain estimates from different sources.

g) use of expectation values. Frequently, societal risks in F-N curves are combined over all consequent damages and expressed as a single damage value (eg expected fatalities per year). On occasion, such use of expected values has created problems for validation of QRA models and has fostered a belief that these models are unnecessarily alarmist when compared to historical experience. This leads to a need for caution in using and interpreting QRA results based exclusively on the expected value of harm, especially when historical data may have been collected over an inappropriate time period, or the work is subject to a significant latency period.

Other quantified approaches are currently being developed for addressing aspects of societal risk. These include

(i) the use of expected (dis)utility criteria (19), which offer some advantages (but with concomitant disadvantages) over F-N curves

(ii) a Risk Index and Scaled Risk Integral approach (20). This approach is very useful in specific local cases, but is limited or not applicable in wider application.

ACCEPTABILITY AND TOLERABILITY OF RISK - DIFFERENT REGULATORY APPROACHES

In attempting to decide upon criteria which regulators can use to judge whether the risk should be incurred (taking account of any benefits) or the amount of resources which might justifiably be deployed, different types of criteria have been deployed. These include:-

utility based criteria, aiming to maximise net benefits, where cost benefit analysis (CBA) is used to calculate the difference in monetary terms between the advantages or otherwise of a particular course of action;

equity based criteria, where the premise of equal rights has led to focussing on protection of the vulnerable; and

technology based criteria, where the level of available control technology is the major determinant in choices as to risk control.

CBA has a part to play in all these approaches; but it is pivotal only to the utility approach. On some occasions multi attribute analysis may have considerable value in decision making where there are significant effects which cannot be expressed in a common (eg monetary) measure.

ABSOLUTE AND RELATIVE RISKS

Another question of importance in communicating risk is whether QRA should express risk in relative or absolute terms. The presence of uncertainty in risk estimation has fostered the belief that absolute risks are simply 'abstractions posing as truth' (21), and that given the uncertainties, only relative risks have any practical value in QRA applications. It may be that what is of interest to the decision maker (whoever this may be) is not the true value of risk, but rather insight gained on the risk involved, whether one activity is safer than another, and the degree to which this might be the case. Because only relative risks are required to answer these questions, uncertainty in obtaining absolute risks would not be relevant.

Notwithstanding difficulties in obtaining reliable estimates of absolute risk, however, the importance of these measures in certain decision situations should not be underrated. Absolute risks are most relevant in setting priorities on the cost-effectiveness of mitigation and in comparing risks to established tolerance criteria. Relative risks are most relevant when one mitigation option is compared with another and the decision maker is interested in some preferred option without a firm statement as to its costs and benefits or its acceptability vis-a-vis public risk tolerance levels, then only risks expressed in absolute terms would be relevant in decision making.

GENERAL PRINCIPLES OF RISK CRITERIA

Whatever the assessed level of risk, the decision maker is ultimately faced with the 'So What?' question, where increasingly quantitative probabilistic criteria are being applied by regulators or enforcers. Where such target criteria are applied (often in a 3-Zone situation, the middle zone embracing the 'ALARA' or 'ALARP' principle) a standard framework is emerging. This framework reflects well established approaches in international risk control, particularly related to advanced, high technology activities, such as those of the nuclear industry, the latter being expressed in the 1977 Report of the International Commission on Radiological Protection. These ICRP recommendations embody the interrelated principles of justification of practice, optimisation of radiation protection, and individual dose limits. No practice or activity involving exposure to radiation was to be adopted unless its introduction produced a positive net benefit in a society, this benefit to be maximised by the 'as low as reasonably achievable (ALARA)' principle, and inequitable distribution at the level of the individual avoided by dose limits for that individual.

Such principles apply, of course, to the control of most risks. In an ideal world, any hazardous activity would not impose risks which were disproportionate to the benefits (such benefits can form a wide spectrum, and inevitably involve economic as well as other, often less tangible, social value parameters), and any such risks would be equitably distributed amongst society in proportion to the benefits received. In practice, of course, such distribution is not possible, and the principles of distribution described above are applied in a much more general way, involving tests to ensure:-

a) whether a given risk is so great, or the outcome so unacceptable that it must be refused altogether; or

b) whether the risk is or has been made so small that no further precaution is necessary; or

c) if a risk falls between these two states, that it has been reduced to the lowest level practicable, bearing in mind the benefits flowing from its acceptance, and taking into account the costs of any further reduction.

These principles combine with other generally accepted tenets:-

d) that risks should never be imposed unnecessarily; and

e) that no individual or community should bear an unfair proportion of any risk.

Such value judgements involve very complex social processes. Hazards and risks are viewed quite differently, depending on the origins of the hazards and the nature of the risks they present. Natural hazards seem to be 'accepted' more readily than those which are man made; and hazards which presage catastrophe appear less 'acceptable' than those presenting a lower level, continuous risk. A relatively well established hierarchy of 'tolerability' has emerged, which involves issues such as:- voluntary vs involuntary exposure, 'natural' vs man-made risks, perceptions of personal control, familiarity, perceptions of benefit or disbenefit, the nature of the hazard or consequence, the nature of the threat, the special vulnerability of 'sensitive' groups, public perception of the extent and type of risk, perceptions of comparators, and the reversibility of effects.

It is a decision hierarchy which turns on the confidence of those exposed to the risks in those authorities and bodies who create and control the risks - government, the regulatory authorities, plant operators, 'experts', and the emergency services. Priority questions include:-

- does the public believe that all views and interests have been considered in the decision making process, or has there been some 'dealing?'
- does the public have the confidence in the effectiveness and independence of the regulatory authorities?
- is there a consistent and credible consensus of scientific opinion about the project that the public can trust, or do the 'experts' disagree amongst themselves?
- what is known about the quality of the project and plant management?
- are the emergency and medical services able to cope with any event, in the short or long term?

It is, in effect, a combination of physical and social detriments, in which some major elements may not be quantifiable in any meaningful way.

CONCLUSIONS

QRA is unlikely ever, of itself, to be capable to mechanistic determination of the tolerability of risk. At present, those methodologies which do exist are subject to uncertainties (which indeed may be greater than the limits of decision making); whilst major elements of the tolerability equation possess no realistic methods, quantified or otherwise, of a sophistication sufficient to produce an integrated or holistic approach. Currently, at best, QRA may allow essentially political decisions to be technically informed.

However, there is some movement towards a more consistent approach for the methodology of quantified risk assessment and analysis, and to its application. Development of criteria will necessarily accompany such progress, and may eventually lead to consistency in the 'tolerability' arena, and in the application of those criteria. Until then, the diversity, complexity and uncertainty involved in the criteria and their use will remain an obstacle to structured risk management, given the pivotal role of criteria therein, and given the sensitivity of decision making to the criteria.

The views in this paper are those of the author, and not necessarily those of HSE.

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THE JOINT RISK PROGRAM AT CEMAGREF

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ABSTRACT : CEMAGREF has been studying natural hazards for many years. Depending on its traditional links with the Department in charge of agriculture, forests and country management, the hazards mostly considered have been forest fires, hazards related to mountain environment (avalanche, torrents and mudflows) and to floods (including dam stability and floods related to dam failure).
In these fields CEMAGREF used to carry out technical studies so as to assist government bodies directly or by means of technical tools as standards and computer programs. Being transformed in 1985 into a research Institute, CEMAGREF gradually entered what was more an evolution than a sudden transformation, since its main center of interest were not changed and applied research was the global task it was assigned.
A significative instance of this evolution is the way CEMAGREF programs evolved in cooperation with different partners in the field of natural hazards, from the above described technical assistance to a comprehesive research program the circumstances of which will be described hereafter.

NATURAL RISKS : FRENCH TRADITIONS AND CURRENT CONTEXT

France has been a very centralized country for many centuries and it is no surprise that natural risks have been mainly dealt with by the central government for as many years. Nevertheless, no country can escape the widespread evolution reducing the role of central governments, handing over their responsabilities one hand to agencies or private sector, on the other hand to locally elected governments. An other aspect is the transfer of power to supranational institutions as European Union, but so far it has not had a significant direct influence in our feld of interest.

For instance, concerning natural risks in mountain areas, in many countries, forest services or agencies are in charge of mountain hazards, the Alpine countries are no exception and France has this tradition. But most of the Forest Administration being transformed into an agency as soon as 1965 (Office National des Forêts - ONF), a kind of hybrid was created to manage mountain related hazards. This entity, named "Service de Restauration des Terrains de Montagne - Mountain Conservation Agency" both depends on government (Departement of Agriculture and Forest) and on ONF. It has both technical tasks (construction works using civil enginering and biological techniques) and political tasks in the field of risk zoning and emergency assistance to the local representative of the central government.
As far as other natural hazards are concerned, the situation is quite similar. Other governmental bodies and agencies play some role in these fields, which have been more crowded than ever since 1982, the landmark date when the central government transferred many powers to locally elected councils heading municipalities, *départements* or *régions*. Natural hazards are theoretically still regulated by central government but for instance most municipalities are totally in control of land planning, deciding which kind of settlement must be promoted in which part of the city, which results in a document called Plan d'Occupation des Sols - POS. Natural hazards have to be taken into account of in the POS, so a negociation between central and local government is an absolute necessity. This negociation results in a an other document, called Plan d'Exposition aux Risques - PER. This procedure has just been modified, so its name was changed. All this proves how difficult this negociation process is.

CEMAGREF HISTORY AND NATURAL HAZARDS

CEMAGREF is a government agency doing resarch in the field of Environment and Agriculture. Concerning natural hazards related to moutain and forest it can be considered as having inherited the tasks of this branch of the Forest Administration which was in charge of technical research in the field of moutain hazards in 1965 then was incorporated into CTGREF as a branch of the technical service of the Department of Agriculture. CTGREF was transformed into an agency in 1981, its name being changed to CEMAGREF. In 1985, CEMAGREF was given the status of "research agency", which implies special conditions for the manpower and subsidies from the Department of Research. In a similar way CEMAGREF inherited some technical and scientific tasks in flooding corresponding to administrative responsabilities of the Department of Agriculture, most of them being meanwhile transferred to the Ministry of Environment. Only through history can be explained that for similar reasons CEMAGREF has a research team working on dams stability and flooding resulting from dam failure.

CEMAGREF ACTIVITIES IN NATURAL HAZARD RESARCH

At least 5 laboratories are active in natural hazards. As a whole these laboratories are staffed by 51 researchers and engineers plus 10 phD. Their tasks, defined in accordance with the general tasks of CEMAGREF is applied research aiming at developing protection technologies and mapping phenomena. Research is carried out in cooperation with universities and other research agencies when fundamental knowledge improvement appears as necessary.
The detail of the activities depends stongly on which technologies and scientific tools are relevant in a given domain. For instance, fluid mechanics applied to newtonian flows is a prerequisite to avalanche and mudflow study. In the same way remote sensing and botanics are fundamental if one is to study forest fire mitigation.

THE JOINT RISK PROGRAM

A brief history ..

The preparation of the joint risk program started in 1993. Its central goal was to improve the internal cooperation between researchers who had few mutual contacts because, resulting from their history as was explained before, most of their contacts they had with their "clients" of the Department of Agriculture and Forest.
To find a common ground for all these research units was not that simple but a consensus was attained about the interest of social science as a common concern and an opportunity to shed new light on researches strictly confined in the field of physical science.
A great help in building this program was provided by the French Department of Environment, not only because it brought funding but also because acting as an outside operator it helped and forced the different research units to work out unified research proposals. The result was a program divided in two main chapters, called "Social science and economics" and "Hazard Mapping". As can be seen in these title, the first part implies much cooperation with non CEMAGREF social scientists whereas the second encompasses themes which are more traditional and familiar to CEMAGREF engineers and reseachers.

The content of the program

The content of the program appears in this table :

Part 1 : Social sciences and economics
  1-a Negociation as the central process of risk mitigation
  1-b Total quality as a tool for risk mitigation
  1-c Tools for negociating flooding mitigation
Part 2 : Mapping
  2-a Methodology
  2-b Time and space related mapping for forest fires
  2-c Vulnerability mapping in the case of avalanche protection by forest
  2-d Typology of maps
  2-e Multi-hazards maps

To fully account for the program negociated with the Department of Environment it is necessary to mention that other topics, of immediate interest, were included which concerned dam stability and avalanche knowledge transfer to Turkey (a joint program with Switzerland in the frame of IDNDR).

Preliminary results

The program starting officialy early 1995, it is not possible to display significative results. Nevertheless, some parts of the program have been at least partially explored in other programs. Combining the results of these programs and the preliminary discussions which have led to the CEMAGREF joint risk program some elements can be exposed as a basis for further research. Considering the preliminary state of the program, one will not be surprised by the unequal stage of development of the different parts of the program. Some of them which are barely started will not be commented .

Social science and economics : Negociation as the central process of risk mitigation. The program is continuation of a joint program started about three years ago by CEMAGREF and CRISES, a research entity depending on the National Center for Scientific Research - CNRS, known for its research in the field of crisis management but mainly for industrial risks (Lagadec 1993). So it is no surprise that the first encounter led to a program dealing with crisis in the field of natural hazards. The first step was to analyze the similarities between the management of crises caused by natural and technological hazards, using two crises due to snowfalls.

The first case was a case of a heavy snowfall creating a week-end trafic congestion on a main highway in December 1990, the second a case of avalanche hazard in a valley leading to the most important ski resorts of France, amonst the largest in the world (February 1991). One central point of interest of CRISES in all cases of crisis was the role played by the different actors and especially by experts (Decrop and Charlier 1992).

The next step was to investigate the role of experts not only in the crisis process but also in "normal time" process, i.e. in every day activity and processes of natural hazards management. This made it necessary to build an other instance of what sociologists call "the risk stage", meaning this stage where all actors meet and interact.

From this situation the research evolved into the examination of the relevant technical tools the actors can use when playing and interacting on the stage of the risk mitigation theater. Mapping, especially hazard mapping appearing both as a very useful and controversial tool it was deemed necessary to construe how maps are actually used in the negociation process. This is the current stage of the research.

Total quality as a tool for risk mitigation : Considering the typology of natural hazards, one possible criterion oppose those hazards caused by physical phenomenon which only produce harmful effects to these caused by physical phenomena which also have beneficial effects and can even been considered as economic goods. The former category is exemplified by earthquakes, the latter by snow avalanches, in which case it clearly appears snow is both the case of major life and property losses but also of great social benefits through the ski industry. Hence the idea to investigate if natural risk mitigation could be a part of quality management in ski resorts having at least considered the possibility of drawing up a quality management procedure. This study has been conducted for approximately four months and the result is inconclusive. It appears that natural risks are to be dealt with in the general context of safety level in a ski resort, which entails also considering problems related to law, insurance...In the same context this study made it clear how even in the largest ski resorts which appear as being managed as big industrial company, local politics exerts a great influence on all decisions.

Tools for negociating flooding mitigation : An other important criterion to natural hazard typology is whether a natural hazard only cause damage to property or both cause damage to life and property. Slow and large floods widespread in the plains of northern Europe being a good example of the first class, a CEMAGREF resarch team has investigated with economists at CNRS the possibility of working out a compromise between the partners acting on the risk stage. The basic idea is to bring out criteria linked with direct economic impacts, which allow for using classical economic tools like preference or indifference curves for given goods, in which case the theory predicts that if the number of actors is large enough one gets the Pareto optimum (Schotter 1994). The resarch was carried out in an experimental way. A preliminary stage consisted in improvement of available tools or creating new ones to represent physical effects of floods, along such parameters like frequency, water depth and velocity, flooding duration. Then using these tools some tests were performed with real problem, i.e. with real rivers, real inhabitants, real elected council. The first results seem promising, as not only a consensus was worked out but it seemed that the tools provided and tested by the researchers greatly helped attain this consensus.

Forest fires: Heretofore a research team at CEMAGREF, working together with different partners (University of Marseille, National Institute for Country, Water and Forest Management - ENGREF, the Meteorological Service) has carried out technological research aimed at forest fire mitigation. Time related problems were addressed combining remote sensing data and meteorological data in order to define danger indexes which are directly useful to firefighters. Space related research takes advantage of remote sensing, and also of wind modeling at regional scale and vegetation mapping to determine hazard maps. Later these maps will be associated with vulnerability maps.

Vulnerability mapping in the case of avalanche protection by forest : Started about three years ago, this research makes an extensive use of G.I.S.. Taking advantage of the functionalities of these systems allowed for mapping forest extension and properties, physical parameters as slope angle, and objectives endangered by avalanches and in some cases rockfalls. From this research a methodology was produced whose main interest is to provide Forest Service with a tool for forest management applicable to high elevation forests with a protective function. As these forests do not have a direct economical interest, it is indeed necessary to bring out relevant criteria to allot public money to their management.

THE FUTURE OF THE PROGRAM

It is quite impossible to know what the outcome of this program will be. Its success will strongly depend on the interactions which will develop in the next three years. These interactions will be made possible by the common use of some tools like GIS and also by the common interest for sciences which have not been developped in CEMAGREF yet, especially social science, economics and law. If some cooperations have been started in the two former domains, the latter is almost entirely to develop and it is a very important one, because courts are more and more severe in France for all the actors of the natural risks stage, experts, government or locally elected officials.

Towards a typology of natural hazards

The main stake is to know whether it is efficient to engage in this kind of joint program regarding natural hazards. In the field of social science, economics, law, insurance this will depend on the answer given to a fundamental question : are physical phenomena so different as landlides, snow avalanches, forest fires earthquakes and floods very similar if they are observed by a social scientist. The first impulse is to answer yes because social scientists first observe how society reacts and are interested in natural disaster as a litmus test of the basic fabric of society (Gilbert 1992). Industrialized societies are very sensitive to any kind of disaster, but their actual impact on society will depend on some intrinsic characteristics partially described. Two possible dimensions already mentioned are this opposing hazards causing fatalities to hazards causing no fatalities, and that opposing hazards related to a physical phenomenon which has no positive effect to hazards related to a physical phenomemon which on the other hand is an economic good. In the latter case avalanche has been taken as an example but other examples abund in the developing world of large crowds living on volcano slopes or along very large and dangerous rivers because there is the fertile soil.

The same analysis will probably help discover other dimensions. An axis of research is certainly the possibility for a phenomenon to happen at least twice in the same way opposed to phenomenon which have not this possibility. This criterion will oppose "meteorological" or "climatic" hazards, like avalanches, floods to "geological hazards", like large landslides and earthquakes. As a general matter of fact any kind of typology only presents some interest if it has practical effects. This criterion discriminates risks which can by dealt with by the insurance market from risks which justify national or local solidarity.

Other criteria are probably relevant to natural hazard typology and they certainly will appear in the exchanges taking place in the frame of the joint risk program now started in CEMAGREF. According to the context described by and large any typology and other kinds of research results anticipated in this program are expected to be directly useful to prepare decisions in several fields like mapping and insurance.

CONCLUSION

The joint risk program opens the door to many expectations, first of all because it sets the groundwork for a large scale cooperation between physical sciences and social sciences, and depending on the way this program was built establishes a relationship between scientists and lawmakers. This program involves research teams, inside and outside CEMAGREF. It is not a closed program. On the contrary, it is open to all kind of cooperation, especially with research laboratories working in the field of social sciences in contexts different from the French one.

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BIOGRAPHY

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MAJOR ACCIDENTS AND DISASTER RESPONSE: THE SWISS PERSPECTIVE

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ABSTRACT

The coordination of the emergency preparedness towards disasters and major accidents takes place into the context of a global security policy. The purpose of this policy is to guarantee the survival of the population and to protect vital installations within a given area (state, region, canton, district, prefecture).

According to the Swiss law - except in the case of a nuclear accident - the authorities of the cantons and communes are in charge of disaster relief in their juridiction. In addition, various instruments subordinated to Federal Departments (i.e. ministeries) can be required either to function as experts or - on request and while respecting the principle of subsidiarity - to contribute to disaster response. Also in peace-time, parts of the army (rescue troops, engineers, medical units, ...) or parts of the means of the civil defence may be involved.

The political authorities in charge entrust cantonal management staffs or parts of them (crisis management staffs) with the mission of managing with disasters or major accidents response.

Disaster response must be considered as a global concept which does not just include immediate relief (rescue). Prevention, precaution and preparedness must be coordinated within an « integrated approach ». The COMCAT - which is a Swiss official commission of experts dealing with disaster response - provides opportunities for mutual exchanges of experiences. These experts are people active in the field of prevention (research, high schools, insurances, humanitarian organisations, ...), in ministeries, at the federal Chancellery, in the cantons as well as in many associations dealing more or less extensively with disaster relief.

In accordance with Switzerland's federal state organisation, each canton has worked out its own structure for disaster response (examples are provided in the paper). Although each of them has its own peculiarities and the available means can vary, several local events in the past few years have allowed them to give proof of their efficiency (Randa/VS, 1991; Brig/VS and Ticino, 1993; Lausanne/VD, 29.6.1994).

INTRODUCTION

« It is in borderline situations only that man become conscious of himself » (Karl Jaspers)

The rapid growth of civilisation in many parts of the world, the technological development and their combined effects on the environment add new types of threats to the dangers that have existed at all times, thus making societies more vulnerable.

In her archives, Switzerland keeps the records that remind her of nature suddenly becoming hostile, such as landslides, rock falls, floods, avalanches, etc., from among I may mention the flooding of Brig, in the Valais, and that of the canton Ticino, in 1993.

Other major occurrences have left their mark on our memories, making us more aware of the new types of dangers:

- Major chemical accidents (fire resulting from the burning of a chemical product warehouse at

Schweizerhalle, near Basle, in 1986);

- Passenger aircraft crashes such as the one occuring at Stadelberg, in the Kloten area, in 1990;
- Train accidents involving inflammables or chemicals, such as in the Zurich suburb of Affoltern or in Lausanne, both in 1993.

We are limiting ourselves to a few major occurrences that have hit Switzerland but could obviously add those that have made themselves felt across the planet, such as Seveso, Tchernobyl, Bophal, etc.

The high population density of Switzerland, particularly in certain sections of its territory, to which must be added all the risks inherent in nature or resulting from the use of technology, cause the topic « disaster » to enter our minds with ever greater alarm.

Disaster of various dimensions and different probability do in fact combine to form a permanent set of risks.

Considering the purposes which the Swiss Confederation has given itself, as stated in article 2 of its Constitution, and taking into account the possibilities and dangers inherent in the global interdepence as well as conditions in Switzerland itself, the *1990 Report on Swiss Security Policy* enumerates the five aims of that security policy. These read as follows:

- **to guarantee peace under conditions of freedom and political independence;**
- **to guarantee our freedom to act;**
- **to protect the country's population and the foundations of its existence;**
- **to defend the nation's territory;**
- **to contribute to international stability, primarily in Europe.**

To protect the country's population and the foundations of its existence: ***« It is our intention to protect within the range of our possibilities our population and the foundations of its existence from all dangers, be they political, military, of natural or man-made origin. »*** (1990 Report, page 30)

BEGINNINGS

As to the measures taken in view of possible disasters, a field in which - as in many other areas - the Swiss cantons have large powers, constant co-ordination on a federal level is indispensable.

In our case, the following needs have been stated:

a) On a federal level
Creating conditions that will encourage a better co-operation at all levels, i.e., with the cantons, with ajoining regions of neighbouring countries, with the countries of the European Union, as well as with international organisations.

b) On the level of the cantons
- Unifying principles and documents.
- Exchanging minutes and conclusions drawn from certain occurrences.
- Making sure that instruction and training are based on uniform guidelines (*« unité de doctrine »*).

It is with reference to these elements that it was decided at the end of 1989 to put up a federal commission called *« Commission for the coordination of preparatory measures in view of disasters »*, better known as « COMCAT ».

As the COMCAT was being constituted, care was taken to include into it as complete a range of organisations, institutions and government offices as possible that might profitably contribute to these efforts.

TASKS

Although the responsibility for the handling of disasters lies with the cantons and municipalities, many federally empowered institutions are also confronted with such tasks.

The means in the hands of the Swiss General Defense, especially those of the Federal Office for Civil Protection and the armed forces can be put to use in times of peace if and when the ordinary means prove insufficient, whereby the principle of subsidiarity must not be encroached upon.

The tasks to be undertaken will be, on the one hand, to study what possibilities there are to improve the ability of the Swiss Confederation to intervene in cases where a disaster reaches national proportions or where help accross national borders is required. On the other hand, the problems related to rescue work in the case of disaster (*« Civil protection »* in EU terminology) make it indispensable to put oneself in a perspective of *« Euro-compatibility »*.

To which must be added the Swiss willingness to participate actively and realistically in the International Decade for the Reduction of Natural Disasters (UNEP / IDNDR) launched by the UNO.

The tasks the COMCAT is entrusted with have been defined as follows:

a) In general terms:
To guarantee a **co-ordinated approach** to the preparation of the various measures aimed at handling disasters and situations of need resulting from natural causes or from technological activities, not including damage resulting from war.
To **develop co-operation** between federal offices and agencies, those of the cantons, the armed forces, the various rescue bodies and scientific institutions.
To create and maintain connections with those agencies of international organisations as deal with disasters, viz.
- UNEP (United Nations Environmental Program)
- UN DHA / RCB (United Nations Department of Humanitarian Affairs / Relief Coodination Branch)

b) To decide on the competence each body has in various cases of intervention.

c) To draft a Federal handbook on the ways in which to handle each type of disaster.

d) To collect and analyse the minutes of major rescue operations that occur both in Switzerland and other countries. To make known the results of such analyses to the cantons and the General Defence partners.

e) To decide, together with the relevant government offices, on what and how much each party involved will have to contribute at an international level, and to co-ordinate the preparations of cross-border mutual assistance.

f) To co-ordinate research and development pertaining to the successful handling of disasters (e.g. « Polyprojekt » at the Swiss Federal Institute of Technology in Zurich: Risk and Safety in Technical Systems).

g) To create a documentary service (with its own data base) whose task it will be to keep federal and cantonal authorities permanently informed.

In all its activities, the COMCAT will have to conform to the principles laid down in the Swiss Federal Constitution, viz.

- **legality,**
- **subsidiarity**
- **and proportionateness.**

COMCAT: MAKE-UP AND ORGANISATION

COMCAT includes representative from following bodies:

- all Federal Departments (= Ministeries) and the Federal Chancellery;
- all cantons;
- the Association of Swiss municipalities;
- the Swiss Federation of Fire Brigades;
- the Swiss Red Cross;
- the Council of the Swiss Federal Institutes of Technology;
- the Swiss Accident Insurance Institution;
- the Conference of the heads of cantonal Police corps.

The Commission meets twice yearly. Its executive staff, comprising its president as well as the representatives of the Swiss Federal Administration, meets, on average, once every three months.

In order to carry out properly the tasks assigned to it, the COMCAT has been given its own permanent secretariat comprising the following working groups:

- **Research and documentation**
- **International co-operation**
- **Assistance given to the cantons**
- **Warning, alarming, rules of behaviour**
- **Standardisation**

ORGANISATION OF THE STAFFS OF THE CANTONS

Within their sovereign territory and the security-policy tasks entrusted to them by the federal authorities, the cantons have to plan, prepare and implement the measures required to master exceptional situations. Particularly in the case of locally limited crises and disasters, cantons and communes are competent as long as there is no need for central action and no federal competences apply; the latter is the case for radioactive contamination and epidemics.

The federal authorities aupport the cantons in their preparatory efforts to deal with disasters, particularly in those cases where sufficient means are lacking or where it is desirable to act in unison.

The prerequisite to successfully master exceptional situations together is a good flow of information. It takes place at three levels:

1) between federal and cantonal administrations,
2) between the emergency staff groups at the federal and cantonal level,
3) and between the Federal Council and the cantonal governments.

If the need to act is very urgent, the canton's participation in the decision-making process may be limited.

In order to act in the interest of the entire country at all levels, close contacts between federal and cantonal authorities are necessary. Mainly in exceptional situations, the latter depend on an early knowledge of the Federal Council's estimate of the situation, on the government's goals, and on the measures prescribed by the Federal Council, so they can solve the problem at their level adequately in time.

In order to master exceptional situations, each canton has formed its own civilian staff. It answers directly to the cantonal government and cooperates closely with the corresponding military staff of the territorial organisation. Larger cantons have similar directives agencies at the regional and district level, in addition to the cantonal directive staff.

Within federal and cantonal legislation, the communes are responsible for planning, preparing and implementing the required measures enabling them to solve the problems arising at their level in exceptional situations (mainly disasters). For this purpose the communal authorities form a directive agency (communal directive staff) wich, according to its instructions, coordinates the preparation of decisions and the employment of means.

In extraordinary situations, there is the danger that instruments of strategic leadership fail or that their means of communication cease to function. In such cases Swiss federalism with its partly overlapping organizational structures proves to be a sort of safety net: if the top structure of one area breaks down, only a comparatively narrow sector is without leadership. Adjoining areas or subordinate levels which are still functionning can bridge the gap as deputies and assure the continuity of leadership. Here **cantons and communes have an extremely important role to play**.

The **army** also makes an important contribution to the protection and conservation of our basic needs. Dangers exceeding the possibilities of civilian means have to be mastered: major disasters caused by nature or man require the deployment of troops and suitable heavy equipment, efficient organisation and prepared management structures.

THE COMCAT IN 1995

As the members of the COMCAT involved in it are on friendly terms with each other, their work has produced results, viz.

a) Internally

- through the forming of working groups;
- through the drafting of a preliminary project concerning a handbook on federal activities;
- through assigning various tasks to the right people with the aim to optimise the co-ordination of the federal government offices involved.

b) Externally

- by establishing contacts with foreign offices and organisations dealing with disasters situations;
- by participating in a cross-border exercise in 1993 (« REGIOKAT », Basle);
- by their willingness to receive and give out information.

FUTURE PROSPECTS

A growing population, the concentration and growth of industry and the services, an ever-increasing number of buildings, all this adds to the vulnerability of our vital systems.

The consequences of disasters can and must be attenuated by preventive measures based on research, the importance of which is beyond any doubt.

Fortunately, researchers in the field show great interest in these activities and I would mention as an example the **National Research Programme n°. 31** (PNR 31) financed by the Swiss National Research Foundation.

Related to these activities, data bases have been created in several countries and on different levels (in Belgium, on a European level, in Federal Republic of Germany, on a provincial, or Land, level). This is an important aspect of disaster prevention deserving co-operation.

Regarding preparatory work, standardising the equipment deserves our attention for it will make assistance much easier. We are convinced of the usefulness of the standardising efforts made on a European level by the rescue equipment manufacturers.

All these activities pertaining to the prevention of disasters and the preparation of assistance in case of disaster add up to a heavy economic burden which may be too great for some states to carry alone. This is why it seems realistic to us to do everything that encourages co-operation on an international level, both in Europe and beyond.

CONCLUSION

As the risks resulting from major disasters tend to reach global proportions, the efforts aimed at finding adequate solutions must be hampered by the erection of dividing walls nor by a spirit of isolationism; what is required is a willingness of societies and states to handle crises and disasters by overcoming political borders.

COMCAT will not only seek to accomplish solid short term goals but is willing to place its activities in a context of growing international co-operation.

TIEMEC '95

Social Science Issues in Emergency Management

Chair:
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DISASTROUS ASSUMPTIONS ABOUT COMMUNITY DISASTERS

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KEYWORDS

Disaster Planning, Community Disasters, Planning Models

ABSTRACT

Planning for local community disasters is compounded with erroneous assumptions. Six problematic models are identified: agent facts, big accident, end of the world, media, command and control, administrative. Problematic assumptions in each of them are identified. A more adequate model centered on problem solving is identified.

That there is a discrepancy between disaster planning efforts and the actual response experience seems rather universal. That discrepancy is symbolized by the graffiti which predictably surfaces on many walls in post disaster locations--"First the earthquake, then the disaster." That contradiction is seldom reduced as a result of post disaster critiques, since the most usual conclusion is that the plan was adequate but the "people" did not follow it. Another explanation will be provided here. A more plausible explanation for failure is that most planning efforts adopt a number of erroneous assumptions which affect the outcome. Those assumptions are infrequently changed or modified by experience.

THE FOCUS

While planning efforts can be undertaken for a variety of social units, the focus here is on planning for a local community response. The local community, as a collectivity, has greater resources to respond to social disruption than do individuals, groups or organizations. Too, the local community is likely to become involved in disaster response prior to involvement of social units in the larger society or in other instances, from the international system. The success or failure of planning effort is more likely to be revealed at the local community level. Too, the local community is a generic form of social organization in every society since it has a territorial base and is organized to solve problems for its population.

The empirical base for the subsequent comments come from an examining of planning efforts and comparing those documents with the now extensive literature on social and organizational reactions in emergency response. There is no suggestion that there is standardization among the various plans, although a common form of planning effort is to copy almost verbatim plans of some other jurisdiction.

The goal of emergency planning is to anticipate courses of action based on projected problems and possible solutions. While the nature of planning should be understood as a social process, for most communities, planning is viewed as the production of a ponderous and detailed document, often prepared by experts, by definition with little knowledge of the community, or by locals, whose primary interest is in creating a product that makes any disaster most convenient for their organization.

One way to evaluate such documents is to infer the various models which guide persons involved in such planning efforts. These models can be inferred by examining the emphasis given to particular tasks. Such emphasis can be determined by the amount of space given to particular themes as well as the lack of attention given to other themes. There is no implication here that one particular model should or will dominate a single planning document. In fact, several models are likely to be combined, often inconsistently, in a single document. The intent here is to analytically separate models which assume certain causes and consequences about disaster and the processes of developing a response. Six models are identified here: the agent facts model, the big accident model, the end of the world model, the media model, the command and control model and the administrative model. They will be briefly identified and evaluated.

1. The agent facts model. Many disaster plans are compendiums of information about potential disaster agents. Much information is not only found within the text but most frequently in the extensive appendices constituting the bulk of the planning document. For example, in many earthquake prone areas, significant portions of planning documents contain lengthy summaries of existing knowledge about plate tectonics, Richter and Mercalli scales, etc. While such information can be important in other educational contexts, there is the explicit assumption that such knowledge is critical in predicting the nature of emergency problems. The tenuous relationship between physical and social damage can be illustrated by the 1988 earthquake in Armenia. The earthquake, 6.9 on the Richter scale, killed approximately 25,000, injured more than 31,000 and left 514,000 homeless. The next year, an earthquake of greater magnitude (7.1), the Loma Prieta earthquake killed 62, injured 3,757 and left more than 12,000 homeless. While information about the social implications of certain agent characteristics, such as speed of onset, warning time, distributional patterns of impact and potential injury patterns can be important, much more relevant is assessing the task ahead in an emergency would be information about population distribution, building and housing patterns and resource availability. The point to be emphasized here is the very low correlation between agent characteristics and consequent social damage, so such attention to physical facts leads to a distorted focus.

2. The big accident model. A second model, frequently advocated when organizations such as the police become the core planning group, is to orient the plan as an enlargement of traditional traffic accidents. Organizations with day to day responsibility for accidents assume the model to be followed is a situation where more victims then usual will be created on site but where there is minimal disruption of the larger social system and little disruption of the societal infrastructure. Using that model, such planning entities assume that their respective organizations will continue to play a dominant role within their traditional domains. The accident model precludes the necessity of altering organizational boundaries to allow a more coherent and integrated emergency response. Most disaster impacts, however, do not reproduce accident effects. Instead, there is usually a diffuse rather than a focalized impact and there is usually disruption of the larger social system and its infrastructure. Consequently, disaster planning, in contrast with accident planning, must transcend the traditional domains involved in routine accidents and develop a more comprehensive interorganizational response.

3. The end of the world model. To a certain extent, this is a precursor to and an extension of the big accident, associated with nuclear war or nuclear power plants. It assumes massive destruction producing casualty rates in excess of the resident population and incapacitates almost all emergency personnel. For some, the model leads to a conclusion that any emergency planning is impossible. To others, there is an effort to save some remnant for a fresh start. Planning efforts usually focused on dealing with mass casualties, moving people out of harm's way by evacuation and/or by crisis relocation, teaching individuals survival skills and providing selected officials with bunkers. The emphasis is on assuring the continuity of government which then would re-establish social life. This process, of course, could only be effective by command and control.

4. The media model. This model is a complex one and probably subsumes several subtypes, such as the Titanic model, the Raging Inferno model, etc. The continuity among the various subtypes, however, is the assumption that disasters are characterized by drastic and traumatic changes in the behavior of "victims." Consequently, people cannot be trusted to behave rationally, except, of course, a few heroic individuals who are also likely to be involved in the planning activity. The model suggests that civil society is very fragile and that disaster events are likely to tip the scales and hasten the decent into irrational, deviant and unlawful behavior. Most people, then, cannot be trusted to assume emergency responsibility.

Given that model, details of appropriate emergency behavior need to be detailed in planning. Too, considerable attention needs to be devoted to issues of security and to the mobilization of emergency workers. The motivation of such workers is seen as problematic since many people will be rendered impassive or seek to avoid responsibility. In general, the media model is individualistic and anti-bureaucratic. Its scripts point to episodes of individual victimization punctuated with celebrations of heroic behavior, overcoming odds and bureaucratic sloth. The media model leads to a slighting of organizational preparedness in the expectation that the most effective response will come from "strong" people. It easily fits with the next model--command and control.

5. The command and control model. This model, of course, historically has had a significant impact on emergency planning because it can be easily combined with other models. It incorporates the assumption that the emergency are quite different than usual social behavior evidenced during "normal" times. It assumes consistent with the media model that the emergency period is characterized by social chaos and is marked by rather irrational social behavior. This is prompted by the loss or

ineffectiveness of traditional social control agencies. Since emergencies produce weakness in individuals and social structure, the goals of emergency planning is to establish command over that chaos and regain "control" of the disorganization of individuals.

This model has a number of implications. First, that ordinary (civilian) institutions generally are incapable of functioning effectively and that families and voluntary organizations are, in large part, irrelevant for emergency action. This means that outside help is likely to be needed and/or that paramilitary organizations, which can quickly assume command and control are the effective in emergency situations. Too, since civilian institutions are weak and break down, the most critical task to be solved by emergency planning is re-establishing "command." So, in many planning documents, a great deal of effort is given to specifying emergency "authority." Since authority in the pre-emergency community is multi-dimensional, the effort to make it unidimensional in emergencies can create community conflict. The usual resolution is for organizations directly involved in the planning process to cede themselves greater authority than other organizations are likely to accord them. However, those claims are usually ignored in an actual emergency. The goal of unidimensional authority is closely related to a notion that decision-making should be centralized, because heroic individuals are likely to be found in small groups at the top. Given that assumption, the desired form of emergency communication is down the authority structure. Such messages are intended to be official instructions to an uniformed and passive population. There is also the notion that "spontaneous behavior," behavior not covered in the plan, is misplaced, misdirected and harmful. In general, then, the command and control model is predicated on the assumption that pre-emergency social structure is weak and ineffective so that details about lines of authority and communication need to be spelled out. There is a distrust of spontaneous action which is seen to undercut planning. The command and control model is still normative for much current planning efforts, in large part because community emergency planning historically emerged from a parallelism with war and, from the fact that many civilian communities assumed that those with military experience had relevant skills to plan for civilian populations.

6. The administrative model. This designation points to the recent emergency of a softer and gentler version of the command and control model. It is eclectic but not necessarily coherent. It draws on organizational theory especially as that theory is understood in public administration. It draws on concepts and ideas relating to information theory to create data and information important to decision-making within emergency organizations. This model does not make a sharp distinction between pre-emergency and emergency behavior. It sees emergency planning as a necessary function of local government, in the same fashion as garbage collection or snow removal. It seeks to utilize modern administrative techniques and advanced technology to facilitate an efficient response.

While the administrative model avoids some of the questionable assumptions in the models, it also has its own blind spots. While it values coordination, its assumptions about the "centralization" of information usually suggests a sanitized version of the centralization of authority. With its concern for efficient organizational functioning, it often becomes paternalistic in tone and action. It also downplays organizational transformation during the emergency period and assumes a simple continuity of organizational action. Because of its emphasis of the generation of information and data, it implicitly accepts a top down communication model. Its organizational assumptions blind the model to the importance of emergent behavior in the response. The emphasis on the generation of information often is uncritical. Data generated by computer programs create the illusion that "real" variables are being manipulated by a key stroke and that those before the screen therefore command the situation and cumulative data does not establish priorities any better than cumulated ignorance. Many of the elements in the administrative model are based on techniques assumed to increase the efficiency of disaster response. However, efficiency may not be the most important criteria for evaluation. A critical argument can be made that an effective response is the most important goal; and, in many cases, maximizing efficiency reduces effectiveness.

CONCLUSION AND DISCUSSION

Emergency planning, historically and currently, has often been hampered by a number of "disastrous" assumptions. Some of the assumptions derived from the emotional content attached to the term disaster. Some of these assumptions are based in mythologies about how people respond to disasters and other mythologies question the capacity of social structures to mobilize an effective response. In general, emergency planners have a rather low opinion of the capacity of individuals and social units to cope. Consequently, much of emergency planning treats individuals and social units as problems rather than resources. Consequently, most assumptions about emergency response focus on the putative need to "strengthen" existing structure, either through the substitution of a more appropriate way to command and control or by suggesting that only through the massive injection of technological aid can community life be salvaged. Most of the models have emphasized discontinuity rather than continuity giving high value to the new and unfamiliar. Most of the models have sought to enhance dominance, rather than to insure coordination. Most of the models have sought to impose rigidity, rather than to enhance creativity. Most of the models have sought to impose artificiality, rather than to continue usualness. These assumptions make emergency planning part of the problem rather than the beginnings of the solution.

A much more adequate model for emergency planning is to recognize that the major tasks in the emergency are problem-solving ones. Existing social units within the community already have had a history of successful problem-solving. Thus the situation calls for decentralized and pluralistic decision-making rather than the centralization of authority and decision-making. A premium should be placed on the flexibility and initiative among various social units and their coordination. The goal of emergency planning should mobilize the problem-solving skills within the community in the most effective way to meet the tasks created by disaster events.

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NATURAL DISASTERS AND PSYCHOLOGICAL ADJUSTMENT: IMPLICATIONS OF RESEARCH FOR PREVENTION EFFORTS

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ABSTRACT

Natural disasters occur frequently worldwide and have a tremendous impact on individuals and communities. This paper presents theory and research on human responses that are directly relevant to preparing for and recovering from disaster. We present a multivariate risk factor model that examines factors that may influence positive and negative functioning after a disaster. We also examine factors that may negatively impact emergency personnel working in a post-disaster environment. Specific recommendations are offered that emergency management personnel can use to plan short-term and long-term intervention programs. These programs may minimize or prevent distress and aid recovery for survivors and emergency personnel.

INTRODUCTION

Natural disasters threaten our health, safety, welfare, and property. Unfortunately, disasters are not uncommon. Between 1900 and 1986, there have been 2,400 natural disasters and 42 million disaster-related deaths worldwide, excluding the United States. Over 75% of all disasters and disaster-related deaths occurred in developing countries (US Agency for International Development 1986). The potential impact of natural disasters is so great that the United Nations declared the 1990's as the International Decade of Natural Disaster Reduction (UN 1987).

Because natural disasters occur frequently worldwide and have a tremendous impact on individuals and communities, it is vital that persons concerned with emergency management understand the human reaction to disaster. "Emergency management is the practice of identifying, anticipating, and responding to the risks of catastrophic events to reduce to more acceptable levels the probability of their occurrence or the magnitude and the duration of their social impacts" (Lindell and Perry 1992, p. 2). Although theory and research concerning human reactions to disaster have paralleled advances in environmental and engineered systems, the findings have not been widely accessible to geographers, geologists, civil engineers, and emergency management personnel because most are published in specialized journals and technical reports.

This paper addresses the need for integration of research findings on human responses that are directly relevant to preparing for and recovering from disaster. Because we take a psychological approach, our focus is on the behavior of individuals who have survived a natural disaster. We examine the disaster characteristics, survivor characteristics (e.g., mental health history), experiences (e.g., separation from family, displacement, injury), and social systems that have been shown to be related to positive and negative functioning after a natural disaster. This is critical in identifying persons at risk for adjustment and recovery difficulties. We also examine the psychological impact of working in a post-disaster environment on emergency personnel. Finally, we offer specific recommendations emergency management personnel can use to plan short-term and long-term intervention programs for survivors and emergency personnel that may minimize or prevent distress and aid recovery.

A MULTIVARIATE RISK FACTOR MODEL

The relationship between natural disasters and subsequent psychological adjustment and recovery can be understood through a multivariate risk factor model

(Freedy *et al.* 1993). According to the model, adjustment is a complex process that occurs over time and is influenced by individual and environmental factors at three stages: **pre-disaster**, **within-disaster**, and **post-disaster**. In this section, we present the model and research findings that support the model.

Pre-disaster Factors

Pre-disaster risk factors exist before the disaster. They include demographic characteristics, prior mental health problems, traumatic events, and stressful life events.

Demographic characteristics. Research suggests demographic risk factors include having limited financial resources, not being able to evacuate before a disaster, and being dependent upon or responsible for other people. Groups that may be at increased risk for adjustment and recovery difficulties include children, parents, elderly, and poorer individuals (Lystad 1990; Raphael and Middleton 1987; Sattler and Kaiser 1994). Research also suggests that women report more emotional distress (e.g., anxiety, depression) than men (Gleser *et al.* 1981; Sattler and Kaiser 1994; Shore *et al.* 1986), and men report more substance abuse and behavioral problems than women (Gibbs 1989; Gleser *et al.* 1981).

Prior mental health problems. Research suggests that individuals with prior mental health problems may be at risk for negative functioning and adjustment difficulties after a disaster. Approximately 20% of the United States population may suffer from a psychological disorder (Regier *et al.* 1984). We suspect that the incidence of psychological disorder may be higher in some countries and lower in other countries. Until additional research findings examine in detail the relationship between prior mental health problems and adjustment, we recommend considering prior mental health problems as a potential risk factor for adjustment difficulties.

Life events. Research suggests experiencing a traumatic life event (e.g., combat experiences, violent crime, serious accidents, natural disasters) may be related to difficulties adjusting to a disaster. This is especially important when we consider that traumatic life events are neither rare nor unusual across the lifespan (Breslau *et al.* 1991; Noris 1992; Resnick *et al.* 1994). It also is likely that rates of traumatic life events may be higher among the populations of certain countries. Other stressful life events, such as unemployment and physical health problems during the year prior to the disaster, may lead to adjustment difficulties (Freedy *et al.* 1993).

Within-Disaster Factors

Within-disaster factors include the victim's experiences during the disaster, including exposure to physical damage and cognitive appraisal of the situation.

Disaster exposure. Disaster exposure refers to the victim's experiences within the first few days after the disaster. Individuals may be at risk for adjustment difficulties if they have little or no warning before the disaster. This is so because individuals will not have time to take self-protective actions (e.g., securing property, evacuating). In addition, individuals who are physically present during the disaster may be at risk of bodily injury and may be exposed to grotesque sights (Green 1990). In general, research suggests disaster exposure may lead to increased mental health symptoms (Green 1990).

Cognitive appraisal. Research suggests that individuals who believe they have little control over the situation, cannot predict outcomes, and believe their lives are threatened may experience emotional distress (Foa *et al.* 1989; Kilpatrick and Resnick 1993).

Post-Disaster Factors

Adjustment can be conceptualized as occurring at two stages: acute and ongoing. The acute stage occurs from the first few days up to four months after the disaster. The ongoing stage occurs from the first few months up to several years after the disaster (cf. Weiss 1993).

Acute stage. Research suggests that positive adjustment is directly related to immediately meeting basic survival needs following a disaster (e.g., shelter, food, safe drinking water, clothing), having reliable means to meet basic needs (e.g., money in savings, insurance, assistance from family, neighbors, friends), and returning to normal daily routines. The loss of material resources (e.g., household contents) and personal and social resources (e.g., sense of optimism, feeling in control, family stability) can negatively impact adjustment (Freedy *et al.* 1992; Freedy *et al.* 1994; Hobfoll 1989). Survivors may experience mild to serious physical and mental health problems. These include sleep disturbances, difficulty concentrating, changes in appetite, irritability and anxiety, lethargy, difficulty with emotional intimacy, lack of feelings, fear of being alone, and pessimism (Baum 1987; Freedy *et al.* 1992; Green *et al.* 1990; Sattler and Kaiser 1994).

Ongoing stage. Natural disasters may produce stressful life events (e.g., unemployment, displacement) that can remain for months or years. The chronic stress related to these life events and the loss of personal and social resources can negatively impact adjustment (Hobfoll 1988, 1989; Solomon and Canino 1990). For example, low levels of social support have been shown to be associated with increased psychological distress (Cook and Bickman 1990). But replacement or replenishment of resources may improve an individual's ability to cope with the post-disaster environment and reduce feelings of distress (Hobfoll 1989).

Survivors may continue to experience or develop mild to serious physical and mental health problems. These include post-traumatic stress disorder, substance abuse, and clinical depression (Freedy *et al.* 1994; Green *et al.* 1990; Rubonis and Bickman 1991; Solomon 1989; Steinglass and Gerrity 1990). Research suggests there is a 17% increase in psychopathology after disasters (Rubonis and Bickman 1991). In addition, disaster survivors may experience increased rates of domestic violence and divorce. Fortunately, most negative psychological symptoms dissipate within 18 to 24 months if pre-disaster conditions return (Cook and Bickman 1990; Freedy *et al.* 1993; Rubonis and Bickman 1991; Solomon and Green 1992). Research also indicates survivors may experience positive reactions, including personal growth and increased self-respect.

Table 1
Risk Factors for Adjustment Difficulties

- Lower income
- Elderly persons
- Prior mental health problems
- Prior violent crime victimization
- Prior history of other traumatic events
- Intense initial emotional reactions to disaster
- Perceived threat of serious injury or death to self or family during disaster
- Higher post-disaster rates of stressful events
- Lack of important resources in the post-disaster environment (e.g., family stability, stable employment, social support)
- Negative coping behavior (e.g., alcohol abuse)

Table 1 presents the primary risk factors for adjustment difficulties following a natural disaster during the acute and ongoing stages. The presence of one or more of these factors may be associated with increased risk for adjustment difficulties (Freedy and Kilpatrick 1994).

PSYCHOLOGICAL REACTIONS OF EMERGENCY PERSONNEL

Emergency personnel (e.g., on-site rescue workers, ambulance personnel, fire and police personnel, doctors and nurses, mental health personnel, administrators) working in the post-disaster environment may be at risk for experiencing negative psychological reactions (Gibbs *et al.* 1993). The relationship between working in the post-disaster environment and subsequent psychological difficulties may be understood in part through the pre-disaster and within-disaster components of the model described above. Emergency workers often have intense and prolonged exposure to harsh conditions, including grotesque sites, and a stressful and chaotic environment. In addition, emergency personnel may have experienced and survived the disaster, lost their home, property, and social support system. Research indicates emergency workers may experience grief, depression, anxiety, distress, difficulty sleeping, loss of appetite, headaches, and body aches (Anderson 1988; Bartone *et al.* 1989; Duckworth 1986; Raphael 1986). In addition, workers may abuse alcohol and other substances (Berah *et al.* 1984; Green *et al.* 1985).

IMPLICATIONS AND RECOMMENDATIONS FOR PREVENTION EFFORTS

The research findings and theory presented above can be applied by emergency managers in practical ways to assist survivors of natural disasters. In this section we offer specific recommendations that emergency management personnel can use to plan and implement preventive short-term and long-term mental health interventions. These interventions may help reduce or prevent psychological distress, and facilitate the adjustment and recovery of disaster survivors.

A number of recommendations are proposed to promote physical and psychological well-being after a natural disaster. We review and elaborate on several recommendations that have been proposed previously (Allen 1993; Dunning 1985; Freedy and Kilpatrick 1994; Gibbs *et al.* 1993; McFarlane 1994; Mitchel 1983; Ochberg 1991), and offer additional suggestions.

1. Early relief efforts (the first 6 months post-disaster) should assist individuals and families in obtaining basic goods and services. Taking care of basic needs can provide a solid foundation for positive functioning and adjustment.

2. Survivors should be encouraged to become involved in collective self-help efforts. Family should help family, neighbors should help neighbors.

Immediately after the disaster, informal networks (e.g., family, friends) may provide assistance to survivors. Disaster plans may include development of informal neighborhood groups that can be prepared to offer assistance in the aftermath of a disaster.

3. Special efforts should be taken to assist forgotten groups. Certain groups, including the elderly, poor, physically and mentally ill, and persons living in rural areas may become isolated following a natural disaster.

4. An important intervention strategy that may minimize or prevent psychological distress is actively educating the public about typical symptoms, and how to cope with the symptoms in the aftermath of a natural disaster. This can be accomplished by having mental health personnel make presentations through the media (e.g., public service announcements, articles in newspapers, television, and radio interviews) and at group meetings (e.g., shelters, community centers, work, churches). This information may reach survivors who might not otherwise seek assistance from a mental health professional. Survivors should be encouraged to share their disaster related experiences with other people.

5. Assistance and recovery programs should be prepared to provide formal mental health services for a full range of psychological difficulties for adults and children. Survivors with certain characteristics (e.g., demographics, employment, injury, experience during the disaster) may be at risk of developing serious mental health problems (see Table 1 for the risk factors). The need for these services may develop within the first few months following the event and continue up to 24 months. In addition, short-term needs (during the acute stage) are likely to be different than long-term needs (during the chronic stage).

6. Disaster plans should clearly define the role of mental health professionals. The plan should consist of teams of mental health professionals who can provide a variety of services, including counseling sessions for individuals and groups (Allen 1993; McFarlane 1994). If possible, mental health professionals should be included in designing the plan.

7. A system to determine whether the services being provided are effective and appropriate should be developed. Feedback might be obtained from community leaders or representatives in the community.

8. It is vital that the disaster plans provide ways to support and reduce the stress of emergency personnel. Personnel who are distressed may not be able to effectively perform their jobs. An effective strategy to assist emergency workers is having mental health personnel conduct debriefing sessions in which workers discuss their symptoms and experiences in the disaster environment, and educate the workers about normal stress reactions and coping techniques (Mitchell 1983). These debriefing groups should be mandatory for all emergency personnel and should continue for several weeks (Allen 1993).

CONCLUSIONS

Theory and research findings suggest that a broad approach to managing the human response to natural disasters is warranted. Each disaster creates new challenges. Survivors are likely to have a variety of needs over time. Most survivors will require information, advice, and reassurance, and many will need assistance securing vital goods and services. A small percentage of survivors may develop serious psychological problems and require comprehensive mental health services.

Emergency management personnel and the engineering community can take specific actions that can promote the health, safety, welfare, and property of citizens and emergency workers. For citizens, intervention programs focusing on reducing or preventing psychological and physical problems should be conducted on an ongoing basis after the disaster. For emergency workers, programs that may minimize vulnerability to negative physical and psychological outcomes should be developed and executed. Before any disaster, training programs for emergency workers should present detailed information on how to perform the job, what to expect emotionally, and how to maintain physical health (e.g., adequate sleep, good nutrition). During the disaster, workers should be given adequate supervision, time off to minimize long-term exposure to extreme conditions, and debriefed about the situation and their reactions. Future research should continue to explore risk factors for psychological distress, and the effectiveness of post-disaster intervention programs for survivors and emergency workers.

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BIOGRAPHY

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THE BEHAVIORAL SCIENCE CONTRIBUTION TO EMERGENCY MANAGEMENT AND ENGINEERING

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Nature may turn out not to be organized into disciplines in quite the same way as universities are - Ackoff

KEYWORDS

Emergency, emergency preparedness, human behavior, behavioral sciences

ABSTRACT

This paper discusses the importance of behavioral science disciplines to emergency management planning and engineering. The authors argue that most emergency response situations, whether simulated or real, occur in systems characterized by both psycho-social and technical components. Those who design emergency systems, whether these are evacuation techniques, decision support technology, fire fighting equipment or other specialized apparatus, often make inexpert assumptions about human behavior. These underlying opinions in turn influence the designers' technical output. Knowledge of the behavioral sciences can provide empirical information, not only on general human response patterns, but about individual and group behavior during emergencies as well. This information allows for more accurate planning and development of system designs. In addition, the behavioral science disciplines can add their empirical tradition to emergency management and engineering, thus providing a template for testing models experimentally.

INTRODUCTION

One consequence of our post-industrial shift toward an information transfer society has been the increasingly complex nature of most human-made systems. Knowledge about these systems based on a Newtonian world view, e.g., that things and people can be divided into discrete categories and controlled, is now being disputed in many arenas. The reason for this wholesale challenge to existing paradigms lies in the fact that they assume a certain amount of independent predictability. When predictions aren't borne out, the explanatory frameworks that rest upon them are in turn brought into question. As systems become ever more intricate, then, their comprehension demands greater levels of sophistication. Insights from any one discipline may now be inadequate to meet these needs.

This concern was expressed by Ab van Poortvliet, et al. (1994:97) in relation to risk management. The authors claimed that most safety issues have been studied from a single discipline perspective. A major drawback to such one-dimensional thinking is that some problems are ignored completely and others do not get resolved. Consequently, planning for large scale incidents involves as much guesswork as anything else. Van Poortvliet and his colleagues thus called for a more comprehensive, interdisciplinary, approach to safety management.

The first step toward achieving a holistic view of emergencies, which happens to be the focus of this article, is recognition that "... the problem nearly always involves working with a total integrated organizational unit" (Herbst, 1974:86). It is extremely difficult, if not counterproductive, to unravel technological, psychological and social factors in describing the causes and responses attending any large-scale real world event. What we need, therefore, is a perspective that specifically rejects our tendency to view problems with the tunnel vision fostered by a particular discipline.

To some extent, socio-technical system theory offers a remedy for one-dimensional thinking. This theory is guided by two principal concepts. First, most task-oriented situations involve a social system of people needed for certain work and a technological system made up of the tools and techniques necessary to get the work done. Second, these interrelated systems of people, tools and activities are in turn part of a larger environment that influences (and is influenced by) the socio-technical system. This open-structure approach to real world situations highlights the need for a basic understanding of organizational phenomena actively and comprehensively rather than passively and piecemeal.

However, one problem with socio-technical system theory, at least in practice, has been the tendency of researchers to focus upon ways to bring a recalcitrant social system in line with an optimized technical layout rather than trying to determine a joint optimization for both (Kelly, 1978). A major reason for this bias lies in the fact that human behavior is seen as too bewildering to predict reliably: "The result is that we are able to specify in considerable detail the requirements of the technical system, but we have no adequate way of describing the social system let alone identifying its characteristics" (Cherns & Wacker, 1978:823).

Yet, as technology gets increasingly intricate and more dependent on information transfer, the need to understand how social systems function will become greater. This demand ought to be especially acute in the area of large-scale emergencies (Robinson, 1982), because the human element is implicated in many "normal accidents" (Perrow, 1984) that occur in complex systems. What alternative exists, then, to taking the social system as a given?

Herbst (1974:88) suggested a very intriguing multiple-perspective model. Rather than viewing any event as composed of physical phenomena on one hand and psychological or social occurrences on the other, he argued there are no exclusive properties: "Every event can be analysed with respect to its role within a network of physical relationships or with respect to its role within a network of psychological relationships, or with respect to its role within a network of sociological ... relationships."

Instead of looking for a way of linking two disparate things, then, the researcher using Herbst's approach would simply need to determine in what way the different modes of analysis used to understand an event are related to one another. In other words, he or she ought to assume the role of *interdisciplinary coordinator.* In that way, the researcher can draw upon various sources of expertise to illuminate a particular problem area.

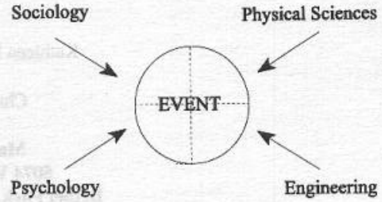

Figure 1: Understanding an event from a sociotechnical perspective

The behavioral sciences have much to offer emergency management and engineering in a multiple-perspective model such as Herbst envisions. First, behavioral scientists helped to develop general systems theory, which fits well with ideas of the socio-technical school. Second, and perhaps as important, behavioral scientists have studied human response to emergencies. In the section following we look at some of these studies and suggest how they might be coordinated with engineering and physical science perspectives on large scale accidents.

INSIGHTS FROM THE BEHAVIORAL SCIENCES

Traditionally, as we know, most emphasis has been on the engineering and mechanics of a disaster though some technical design studies have included the human element. An example is "Time of Evacuation by Stairs in High Buildings" (Galbreath, 1969), which focused on the movement of people. However, it did not consider such variables as evacuation speed, or other factors that might influence choices of direction. Historically, then, human behavior was "fit" into the appropriate "bits" found suitable for an engineering paradigm.

Grosdeva and Montmollin (1994) performed numerous studies to analyze what happens when nuclear plant operators are confronted with technical malfunctions. These authors put more emphasis on the operator's qualitative competence (knowledge and reasoning) than upon the quantitative reliability studies which measured their actions. Grosdeva and Montmollin believe that while the latter can inform us about ill-fated behaviors, the former will yield important information about *why* the actions were taken. When the *why* of human-machine problems is sought, we move beyond a mechanistic representation of human response and enter the domain of the behavioral sciences with their empirically sound methods for testing procedures.

What can the behavioral sciences contribute to the emergency field that will allow us to go beyond simplified representations of people's responses? What kind of useful information might a system designer glean from a systems approach that embraces the tenets of human behavior? To address these questions, this section will focus upon a brief overview of studies that deal with three different dimensions of actions during critical events: the notion of group effects; leadership in escapes; and panic behavior.

The Notion of Group Effects

Human behavior may be viewed from an individualistic perspective - traditionally the focus of psychologists, or from a group interaction perspective - the interest of social psychologists and sociologists. Generally, disasters involve groups of people who are interdependent during escape, meaning that there is a need for people to work together to escape or evacuate.

Studies were reported by Kelley et al. (1965) on laboratory simulations of one type of group escape situation. Each group of subjects was given a limited amount of time to escape from an electric shock by depressing an escape switch that only worked if other members of the group were not pushing theirs. They were able to escape only one at a time thus creating a situation of mutual dependence. The researchers found that when members of a group took their cues from each other, one of two things happened: if there was little optimism about escape, interaction proved to be harmful; but a high level of optimism was reinforced by interaction and resulted in successful escape. In addition, the authors found that public expressions of confidence reduced anxiety and greatly increased the percentage of people who managed to escape. If there was a sign from one or more subjects that they were willing to wait, successful escape increased.

The "Affiliative Model" (Sime, 1983) predicts that in life-threatening situations individuals will be concerned not only with self preservation, but will experience an increased concern for other group members. McPhail and Wohlstein (1983:594) supported this notion in their work suggesting that "... most individuals assemble and remain with friends, family or acquaintances. Those social units constitute sources of instruction and sanctions for the individual's behavior." Turner and Toft (1989:177) pointed out that during the Summerland Leisure Centre fire individuals based their actions on family group membership: "Instead of immediately escaping themselves, ... many parents desperately looked for their children frequently causing additional confusion ..." The authors concluded that "... individuals with close psychological ties will attempt to escape in groups of two or more."

Similar findings were reported in the study of the Beverly Hills Supper Club fire (Johnson 1987). Interviews showed that even when family relationships weren't present the survivors reported escape by groups and frequently used the names of others in describing their escapes.

The presence of other people influences responses and response time. It has been suggested that attachment or affiliative behavior has survival value (Bowlby, 1973 in Sime 1983). Gaining proximity may be interpreted as providing a protection from threat. Knowing that people tend to seek out others in a crisis provides the emergency planner with important data. Humans do not escape four abreast down a stairwell at the first indication of an emergency. In planning evacuation time, needs, and equipment, human interaction in crisis must be taken into consideration. In addition, the interaction between people is important in the choice of exits as people tend to follow the route that others are using (Hodgkinson, 1990). Thus, in reality, people will not divide into equal groups utilizing each available exit, as in the model of "bits" of human behavior engineered to fit the situation.

Leadership Behavior in Escape

Simulation models have been created to study human response (specifically leadership behavior) in emergencies. Hayashi (1988) created a computer simulation model to aid in planning disaster prevention by evaluating leader behavior in a fire. The model was designed to judge the actions and thinking of leaders. The simulation consisted of a maze with a leader, an informal leader and 50 evacuees. This simulation was run four times each by 101 subject-leaders. The results indicated that the leader actions were not dictated by circumstances but by the individual characteristics of each leader, leading the author to conclude that an evacuation plan should not be based on circumstances but should consider the anticipated behavior patterns of leaders. In addition, the study showed that the worse a situation gets the less salient are individual differences.

What can this mean to emergency managers - to base an evacuation plan on the *anticipated* behavior of leaders, not on circumstances? This is exactly the type of recommendation from the behavioral sciences that creates consternation for the emergency manager. Yet, knowing that effective escape leaders make decisions logically - based upon available information, the manager can evaluate the probable information available to the escapees and *anticipate* logical behavioral responses thus fulfilling the role suggested in Herbst's model, of the interdisciplinary coordinator.

An analysis of leadership behavior during escape from several U.S. underground mine fires resulted in a profile of six leadership characteristics. The leader of each escape was described as an aware, knowledgeable person, alert to his environment, attentive and discerning whose leadership emerged in a natural way. The leaders were decisive, yet flexible and open to input from others. Effective leaders seemed to have a calming effect on their group. Finally there was a logic to their leadership; logical decisions based upon available information (Kowalski et al., 1994).

Panic Behavior

The panic model says that people will revert to highly primitive, self-preservation behavior, ie., "every man for himself." This inaccurate assumption, accepted as a general human response pattern, has figured implicitly or explicitly in fire regulations. Contrary to "common belief", however, panic is not automatic in fire or other crises (Johnston and Johnson, 1988; Hodgkinson, 1990).

In a laboratory computer simulation Misumi and Sake (1982) used one accomplice leader and four naive subjects. Each subject could move his or her assigned red dot on a display. The results indicated that if the leader first attempted to reduce tensions and then indicated the direction of escape the subjects followed more closely than if the sequence of behaviors was reversed. The authors concluded that panic is reduced by introducing appropriate leadership.

There are many variables that mitigate the "contagious emotion" that is usually defined as panic. In fact, researchers have generally concluded that individuals will panic and try to save themselves at the expense of others *only* when a situation is *extremely* threatening (Sime, 1990).

DISCUSSION

Clearly, the behavioral sciences can contribute important insights to those charged with managing emergencies. The research presented here, for instance, supports the contention that emergency activities (including escape) are not individualistic, they tend to be group responses... thus we must look toward models based upon group interaction data. In planning for emergencies we must take into account the anticipated behavioral pattern of collectivities (Levit, 1988). The behavioral sciences can offer this piece to a total systems approach.

Yet, it is short-sighted to simply add new disciplines and information or divide the various functions of emergency management into "bits" to be entered with the expectation of producing a "whole". In true systems philosophy, the sum of the parts is greater than the whole. A socio-technical approach challenges the manager with the task of coordinating the *gestalt* of a multi-disciplinary endeavor.

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SWISS NATIONAL RESEARCH PROGRAMME 31 (NRP 31) : « CLIMATE CHANGES AND NATURAL DISASTERS »

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ABSTRACT

The objective of the NRP 31 is the detailed study of the mechanisms and consequences of future climate changes in the Swiss environment, and the resulting interactions between climate, the water cycle, natural hazards, ecosystems and society.
This programme should help improve our understanding of the response of the environment to abrupt short-term climatic events and to long-term climate changes, and provide answers to economic and political decision making. The emphasis of research will be on processes acting on the regional scale, especially in the Swiss Alps. A particular attention will be given to interdisciplinary studies. There is an attempt to bring together specific projects in especially sensitive geographical test-zones, as representative as possible of Swiss conditions. Numerous applications of the research supported by NRP 31 are envisaged, results will be continuously subject to detailed and realistic assessment.
As an example of this approach, the flood events which affected the town of Brig in the Swiss Alps the 24 September 1993, will be presented and discussed in detail.

INTRODUCTION

Our environment is a dynamic system which operates both in the short term (for example extreme weather events) or in the long term (climate processes). While natural catastrophes are often caused by unpredictable extreme perturbations, causing destructive effects on local or regional scales, climate changes operate on far larger spatial scales and impact upon the natural environment and also, in the long term, on socio-economic systems.
The general public, the media, as well the national and international policy-makers are becoming increasingly concerned by such problems, as exemplified by the United Nations Conference on Environnment and Development in Rio de Janeiro in June 1992. As a conclusion, the potential impacts of abrupt climate changes are sufficiently important to justify immediate negotiations, even if many uncertainties remain as to the nature and amplitude of climate changes in decades to come.
In this context, the Swiss Federal Council approved in June 1990, the NRP 31 Programme on *«Climate Change and Natural Disasters»*, which is financed by the Swiss National Science Foundation. This programme represents a Swiss contribution to international research efforts on this theme, and is coordinated for example with the UN International Decade on Natural Disasters Reduction (IDNDR). NRP 31 brings together fundamental research, interdisciplinary studies, and policy response strategies in order to provide a scientific framework for economic and political decision making on the national level.

DESCRIPTION OF THE SWISS NATIONAL RESEARCH PROGRAMME 31

Context and Objectives

The principal objective of the NRP 31 is the basic study of climate processes in the alpine region - both in present-day climate and in a changed global climate - and the detailed examination of the consequences of possible futures climate changes. This programme should help improve our understanding of the response of the environment to sudden short-term climatic events as well as to long-term climate changes, and then to test how society and politicians react to these events in Switzerland (NRP31 1992).

Climate changes represent one of the major environmental preoccupations of this decade. Conclusions of the IPCC - Intergovernmental Panel on Climate Change - (Houghton *et al.* 1990, 1992) predict an alarming increase of the atmospheric temperature on the earth. The ground-level atmospheric temperature has increased globally by 0.3 to 0.6 °C since the middle of the last century, although there is yet no clear indication from observations of a direct link between emissions of greenhouse-gases from industry and agriculture and this global warming trend. Nevertheless, if this trend is confirmed, predictions for the future are pessimistic : a rise of 1 °C by the year 2025 and about 3 °C by 2100 (0,3 °C per decade) with the IPCC scenario A: *«Business as usual»* (Houghton 1990, 1992). This is a rate of change 10-100 times greater then natural climate variability.

Specific model calculations for future climates in 2030 for the Southern Europe, based on a doubling atmospheric CO_2-concentration scenario (IPCC-A), reveal trends of increasing mean temperatures, especially in summer (+ 2 to + 3 ° C), and increasing precipitation sums in winter (+ 5 %) but a marked precipitation decrease in summer (- 5 to - 15 %). These trends are consistent with present-day hypotheses concerning greenhouse-gas forcing of the climate system.

Conclusions of the IPCC on the global scale will have also effects on the regional alpine scale, which will also be sensitive to climate changes. If the expected global warming is confirmed for the next century, we can forecast for example a spectacular retreat of the glaciers (up to three quarters of the present surface area), an upward migration of the permafrost boundary (200 to 700 m) and of the snowfall level (150 to 300 m), a change in the precipitation régime, an acceleration of the water cycle (water discharge), an increase in frequency and size of storms, a loss of biodiversity, etc. Under climate changes, the risks of natural disasters may grow in frequency and intensity for the next decades : storms, heavy rainfalls, floods, mudflows, landslides, rockfalls, avalanches, glacial damage and forest fires (resulting from greater aridity). On the other hand, natural disasters are also caused by a combination of different unfavorable factors linked to human development (settlements or change in land-use). These disasters will have more serious effects and increasingly affect areas that have so far remained untouched by such phenomena. From an economic point of view, costs due to more frequent natural disasters may be enormous, for example one can mention investments for protection infrastructures or impacts on mountain economies (changes in ecosystems, agriculture, forestry, land-use and tourism, especially winter skiing).

The problem of climate change on the regional scale and its resulting interactions between climate, ecosystems, natural hazards and society is the main thrust of NRP 31 activities. Numerous applications of the research supported by NRP 31 are envisaged. The emphasis of research will be on processes acting on the regional scale, in which the Alps and their interaction with their surroundings will be a major focal point. The completion of the programme is scheduled for 1997. To date, 50 research groups are taking part in the NRP 31, coming from Swiss higher educational institutes (Universities and Federal Institutes of Technology), administration, private research firms. A particular emphasis will be given to interdisciplinary studies. In order to encourage cooperation between researchers and facilitate the collation of results and their applications, five project groups have been formed. The Fig. 1 summarizes the main themes examined in each group (NRP31 1992).

Consequently, it will be attempted to bring together specific projects in especially sensitive geographical test-zones, as representative as possible of Swiss conditions. Three regions in the Swiss Alps have been designated for this purpose, characterized by a concentration of research projects (areas situated in both French and German parts of Switzerland). Throughout this period, research results will be continuously subject to detailed and realistic assessment of the risk potential under changed climatic conditions, and a sound assessment of the policy response strategies.

NRP 31 investigations are now in progress and will completed by the end of 1996. We propose here to discuss rapidly two aspects concerning climate changes, especially warming, derived from the first available results. In the next two chapters, we will first focus on features of observed climate in Switzerland since 1901, then we will discuss a practical example of crisis management, taken from the flood disaster which affected the town of Brig in the Swiss Alps in September 1993.

Figure 1 : Summary of the main themes examined in the research groups of the NRP 31.

NRP 31 Groups	*Themes*
CLIMATE	Historical climate data, post-ice age climate history reconstruction (in lacustrine sediments and ice cores), simulation of present and future alpine climate, regional scale climate data (downscaling methods).
WATER CYCLE	Flow discharges, water régime in ground and snow cover, karst and ground-water reservoirs behaviour, dimensionning of hydraulic works, heavy rainfalls, hail, monitoring with radar technology, dynamic of storms.
NATURAL HAZARDS	Processes of ice and snow melting, glacier fluctuations, icefalls, avalanches, permafrost evolution, drainage processes in torrents, floods, mudflows, climate influence on landslides, rockfalls and rockslides.
ECOSYSTEMS	Impacts on soils and roots, modification of vegetation types, reactions to a rise of atmospheric CO_2-concentration, simulation of changes in ecosystems, impacts of storms, forest fires.
SOCIETY	Social, economical, political, and administrative aspects, land-use planning, risk and disaster management, impacts on tourism and agriculture, damage statistics, risk perception of population and decision-makers.

First Results : Lack of Snow and Retreat of Glaciers

For the first time in over 300 years, 7 successive years with little or no snow were recorded on the Swiss Middlelands between 1988 and 1993. Is this an indication that winters in Switzerland are subject to warming which exceeds the mean climatic variations of the past? Written historical records since the late 15th century, and data from the climatological network of the Swiss Meteorological Institute, provide the longest information on snow statistics in the world *(NRP 31 Project Pfister: "Space-time reconstruction of weather anomalies").* These data confirm that winters in the late Middle Ages were colder and had more snow than today. During the Little Ice Age, which ended around 1880 - 1890, the duration of snow cover on the Swiss Middlelands averaged about 60 days per year. During the 20th Century, average snow duration has been about 46 days, and only 20 days in the past seven years. However, it should be emphasized that the increasing tendency for snow-free winters observed since 1988 should be put into the perspective of other periods of lack of snow which have occured in the past, as will be seen in the next section.

Another effect of global warming is associated with the retreat of mountain glaciers. The morphology of Swiss alpine glaciers has undergone profound modifications since 1850, and this will continue to be the case under expected climate change conditions. Warming has pushed upwards the average level of snowfall by about 100 m, and has resulted in a spectacular retreat of glaciers in which over 35% of their surface area has been lost since 1850. If this tendency were to persist, then the retreat of glaciers would accelerate, leading to the disappearance of many glaciers, in particular the smaller ice fields; an increase in mean temperature of 1.8 °C would be sufficient to reduce the number of existing Swiss glaciers by 80% and total surface area by 70% with respect to today's situation. It is estimated that in the next 25 years, the surface area of glaciers in Central Switzerland (Gotthard and Grisons) will diminish by about one-quarter. In these regions, one glacier out of eight will have disappeared by the year 2020, and by the end of the 21st Century, only one-fifth will remain *(NRP 31 Project Maisch: "Impacts of climate changes on glacier surfaces: Scenarios of the retreat of glaciers).*

However, this situation, as in the case of snow statistics, is not exceptional. In the last 10,000 years, similar or even stronger glacier retreats have occured. Nevertheless, the evolution of climate and its influence on snow and ice, plays an essential role in the present socio-economic context in terms of mountain tourism and the ski industry, where considerable investments have taken place in recent decades. Climate change will result in a reduction in the ski season (from January to March) and in an increase in skiing on glaciers or on snow fields at higher altitudes above 1500 m *(NRP 31 Project Elsasser: "Effects of climate change on tourism").*

CLIMATIC ASPECTS IN SWITZERLAND

What are the consequences of the IPCC conclusions on the Alpine scale ? Unfortunately, current prediction tools (General Circulation Models) have an insufficient spatial resolution to be applied directly on a local scale, for example to a mountainous region as the Alps. Several approaches are being tested, as part of the NRP 31, to establish a link between global and regional atmospheric scales («Downscaling» procedures; Beniston 1994). Final results will be available by the end of this year. We prefer to present here features of the observed climate in Switzerland, from the climate data available for the last hundred years (1901-1992; Beniston *et al.* 1994a, 1994b; *NRP 31 Project Roten : "Spatial resolution of climatic modifications in the Alpine domain"*). In this country, climate data have a space and time distribution which gives a relatively precise idea of the climatological evolution on a regional scale since the beginning of the 20th century (1901), or even earlier for certain stations (since 1864). The Swiss Climate Data Base of the Swiss Meteorological Institute comprises one of the densest climatological networks in the world with over 150 stations over the Swiss territory (approx. 41'000 km^2).
The complexity of Alpine climates in terms of macro-scale features is brought by the competing influence of Mediterranean, continental, Atlantic and Polar régimes. Any response to global climate change will result in the altered frequencies of these principal régimes, possibly leading to an amplification of the regional response of climatological variables (temperature, precipitations, sunshine duration, snow depth, pressure).

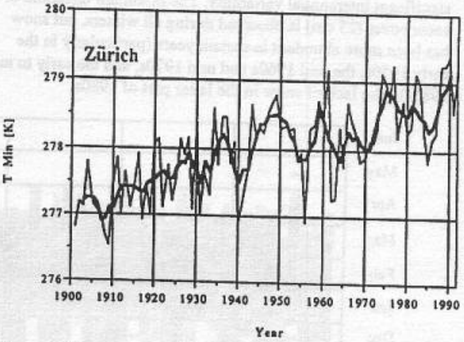


Figure 2 : Average annual daily minimum temperature trends in Zürich, 1901-1992, the bold line represents a 5-year filter function to remove high-frequency fluctuations from the data.

Fig. 2 provides a graphical representation of the evolution of daily minimum temperatures at the station of Zürich from 1901 to 1992; a five-year running mean has been applied in order to filter out high-frequency fluctuations from the data (Beniston *et al.* 1994a, 1994b). At this station, minimum temperatures have increased continuously by about 2 degrees during this period, especially in the early fall and in the winter. Maximum temperatures remain essentially unchanged and exhibit even a light decreasing trend especially between 1940 and 1980 (- 1 °C). As a result of these observations, the diurnal range of temperature has tended to decrease on an annual average basis from 9 °C at the beginning of the century to about 7.5 °C today. This fact has been reported in other analysis studies for the Northern Hemisphere, and is also consistent with model studies of greenhous-gas induced warming (Beniston *et al.* 1994a, 1994b). Since the mid 1980s, the annual trends of increasing temperature in Switzerland are therefore in accord with the global warming tendencies, but the rate of warming far exceeds that of the global tendencies. Nevertheless, the Swiss data indicates that the 1940s were the warmest decade of the century (1.5 °C/decade rate of warming), more so than the 1980s (1 °C/decade), when the 1960s and 1970s revert to cooling (- 1 °C/decade). When all the records are combined together, the net effect over the century is a warming, which is also consistent with the IPCC projections.

The data for precipitation show no significant trend over this century in Zürich and in other Swiss stations, while sunshine duration shows a general tendency of decreasing through the century until the early 1980s. However, these two variables exhibit very noisy time-series, reflecting strong interannual variability in the Alpine region.

Fig. 3 gives an overview of the occurrence of snow cover in the Alpine village of Davos (1590 m) during the period from 1931-1992, for three thresholds of total snow depth (25, 50 and 70 cm respectively). The main comment concerning the snow depth is that, even in a high-altitude resort as Davos, there is a significant interannual variability. The minimum threshold of snow cover (25 cm) is observed during all winters, but snow has been more abundant in certain years (particularly in the early 1950s, the mid 1960s and mid 1970s, and the early to mid 1980s). The lack of snow in the latter part of 1980s, culminating in the winter 1989-1990, which raised considerable media interest and led to financial difficulties for low-altitude resorts (under 1500 m), was not in itself an exception. There have been other periods in which snow has been lacking in terms of snow duration and abundance (for exemple 1978-1979).

During the most part of the century, the annual average pressure mesured in Zürich, representative of the large-scale pressure field over Switzerland, has fluctuated within a range of 949-951 hPa. Since the beginning of the 1980s, however, the surface pressure has increased continuously to reach values beyond 952 hPa. Persistent patterns of high pressure episodes and extended periods of blocking highs can be also identified in the records toward the 1990s. This pronounced increase of pressure since the decade of the 1980s seems to be related to a greater frequency of blocking high episodes in the Alpine region, especially during the winter season, which may be indicative of a shift in the relative occurences of typical weather régimes over the Alps in recent years (Beniston *et al.* 1994a, 1994b). On the other hand, the behavior of pressure in Switzerland seems closely associated with periods of blocking episodes related to North Atlantic Oscillation Index (NAO is a measure of the strength of the Westerlies over the North Atlantic), confirming the link between the global and the regional scale.

The periods of persistent high pressures, especially towards the end of the 1980s, were accompanied by low snow depth. This reflects the fact that snow precipitation during episodes of blocking high pressures was insufficient to allow snow to accumulate to the depths generally attained in other years of greater snow abundancy.

Figure 3 : Time-frequency diagram of snow depths in Davos for 25, 50 and 75 cm thresholds. The vertical extent of the bars corresponds to the duration of the events.

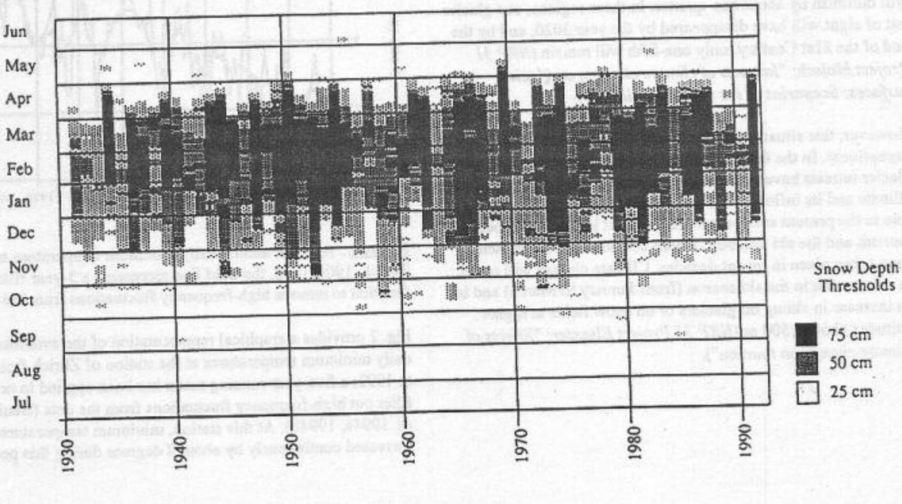


Fig. 4 shows that the beginning of the snow season in the Alpine village of Davos (for the 25 cm threshold) underwent a change from the 1930s to the early 1970s, when the snow appeared as much as one month earlier in the 1970s. In the last 20 years, however, the beginning of the snow season has reverted to its values of the 1930s. The duration of snow cover in excess of 25 cm has an inverse relationship : there was a marked increase in the duration of the snow season from 1930s to 1970s (130 days to 160 days with continuous snow cover), then a return to the 1930s values in the 1980s. The winter 1989/90 was the period of least snow duration of the recorded data (98 days). It should be noted that geographical aspects (slope orientation and exposure) are quite important for the distribution of snow in time, which is often a regional feature.

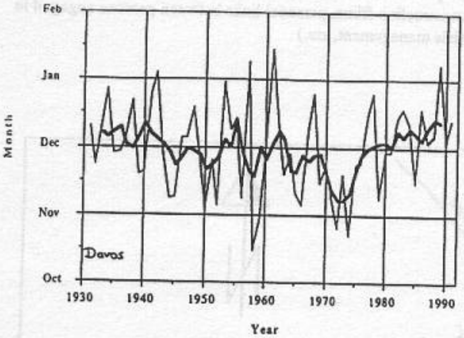


Figure 4 : Evolution of the beginning of the snow season in Davos, 1930-1992, the bold line represents a 5-year filter function to remove high-frequency signals from the data.

In conclusion, for all climatological parameters, it appears that the amplitudes on the regional scale are much larger than on the global scale, but it has been established that there is indeed a regional response or a regional sensitivity to global changes, especially in the 1980s (high pressures in fall and winter). All variables, especially the snow depth, exhibit strong interannual variability with decadal-scale fluctuations. On the other hand, sunshine duration, precipitation and to a lesser extent temperature, anomalies are particularly well correlated with the pressure anomalies for the North of the Alps. There is thus some evidence that climate trends in Switzerland are consistent with global warming tendencies.

Correlations between high-elevations stations are quite good and serve to support the hypothesis that the same climatic change is leading to the same kind of response within the Alps. This gives the possibility to cluster Alpine climate stations into groups of similar climates on a regional scale. One significant difference concerns the South of the Alps which exhibits a different climatic régime dominated by Mediterranean-type climate (precipitations and temperature), the Alps acting as a significant barrier to the westerly and northerly airflows.

CASE STUDY : FLOOD DISASTER IN BRIG/ WALLIS - SWITZERLAND (SEPTEMBER 1993)

General Context (Kunz 1993)

On September 24, 1993, the town of Brig and the region of Upper Wallis in the Swiss Alps were struck by catastrophic floods. These events were linked to a meteorological situation characterized by a warm and moist depression moving in from the Western Mediterranean. This perturbation was blocked by the southern slopes of the Alps and resulted in intense and continuous precipitation for 5 days (approx. 400 mm total rainfall). Because of the high level of the 0 °C isotherm (3,000 m), precipitation was not retained at high elevations as snow. As the soils had exceeded their saturation limits, surface runoff resulted in an intense erosion of the river basins and a rise in the river levels leading to severe flooding; the return period of such events is estimated at between 30 and 70 years. In the town of Brig, the discharge of the Saltina river rose excessively, as well as the sediment load whose volume was estimated at 250,000 m^3.

In meteorological terms, the intensity of precipitation recorded during this event was not in itself exceptional. The catastrophic flooding in Brig was more the result of construction (under-dimensioned bridge) and urbanization with excessive building in sensitive zones. 20,000 people were affected by these floods, but only two people lost their lives. Estimates of damage costs are in the range of 500 million Swiss Francs (US$ 380 million).

The Brig Flood Event (September 24, 1993)

Following three days of continuous rainfall, the Saltina river which originates in the Simplon Pass area, began to threaten the town of Brig through which it flows. On September 24, 1993, around noon, the level of the river was very high beneath the "Saltinabrücke", a bridge 70 m large. At 2 PM, the police and fire brigades were on full alert. Around 4 PM, the river and its load of gravel and rocks, had more and more difficulty in flowing beneath the Saltinabrücke. The excessive sediment load began to block itself beneath the upstream edge of the bridge, thus immediately forming an obstacle to the flow. At this stage, the Saltina flowed out of its bed. This is located on an alluvial cone, so that the flood waters followed the line of maximum slope, thereby flooding neighboring settlements and in particular the town of Brig, where the main streets were invated by thousands of cubic meters of sediments (Fig.5).

During the alarm phase, the population was requested to leave the buildings, in particular the ground level and cellars. However, these recommendations were only partially followed, and most people were surprised by the swift arrival of the flood waters. The first reactions were to place sand-bags on the Saltinabrücke and to use bulldozers to dig out the river bed; it was soon obvious that these measures were of little use.

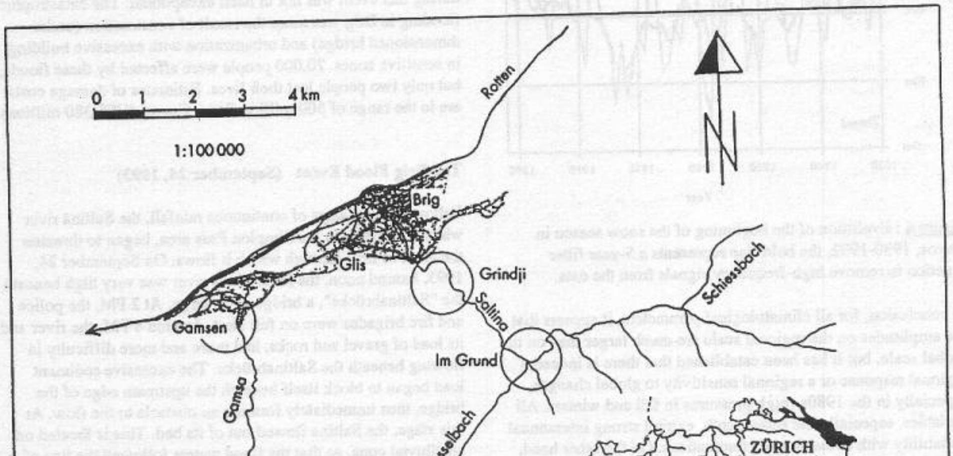
The Brig fire brigade managed to set up a minimum coordination infrastructure within the first hours of the disaster, rounding up 60 local firemen. In parallel, other organizations such as the Civil Defense and the Swiss Lifeguard Society came into action, followed by spontaneous actions on the part of small firemen's groups. These latter contributions are difficult to evaluate, but confirm the capability of the various firemen's divisions to organize themselves rapidly and spontaneously in an independent manner.

From the moment that a crisis unit was set up, a major coordination effort of all brigades was attempted. One of the first effective measures to reduce the flooding was to build a wood and gravel dam on either side of the river. The work to tame the Saltina was carried out by a local construction firm and lasted all night. The river bed was slowly cleaned and emptied, after three and a half days of uninterrupted work.

Local Crisis Management (Zimmermann and Müller 1994)

Even though there had been crisis management exercises, the executive authorities of the town of Brig had no first-hand experience of how to manage such a catastrophe. The chief of staff of the crisis unit was the president (mayor) of the town of Brig. The first meeting of the unit took place on September 24 at 5 PM, at a time when the tasks and representativity of the persons present was not yet clearly defined. The first meetings of this crisis unit were poorly structured and the decisions taken were vague; much improvisation was required in view of the unusual situation. However, it became clear that one of the main tasks of this unit was to avoid panic in the population. In order to remain efficient and to face up to complex problems, an optimal use of existing structures was encouraged (construction frims, personal links between persons engaged in crisis management, etc.)

Figure 5 : Location of the Swiss town of Brig in its surroundings with the drainage basin of the river Saltina.



From the start of the events, the local radio station (Radio Rottu) played a leading role in the broadcasting of information at a time when other means of communication were cut. The search for missing persons also took place with the help of the station. At a later time, official communications for the press, the radio, and television were the responsibility of the chief of staff of the crisis unit, who had to take into account difficulties related to verification of information. Caution was required to counter the tendency of the media to look for "spectacular" information only. A "communications triangle" was thus established, each with its own problems: the crisis unit (credibility), the media (competition) and the population (insecurity); the latter two tended put to pressure on the crisis unit to take immediate action.

24 hours after the event, the crisis unit needed to be restructured, because the management of the catastrophe now required more professional management, organizational and technical expertise. At this stage of the organization, it became obvious that the crisis unit, and in particular its chief of staff, required full powers while at the same time retaining a unified decision basis. This type of managemenent may appear somewhat totalitarian but is in fact well embedded in the Swiss social traditions. The crisis management thereby higlighted the central role played by the chief of staff, i.e., the president of the town of Brig. His knowledge of the area, his popularity at the local and regional level, his political capacity, his military experience, and generally his natural authority made him a principal actor, also with respect to the cantonal and federal authorities. The president of Brig was later an essential figure during the phase of financial compensation for flood damage by private insurance companies and by the Swiss Confederation.

The crisis unit divided itself at that time into several sections, each responsible for a particular activity: construction and safety, coordination, finance, supply, insurance and compensation, etc. The coordination section was aimed at overseeing the three aid organizations: the fire brigades, the civil defence, and the army, all incorporated into a civil and military structure. Essential tasks needed to be carried out according to a set of priorities; safety, search for missing persons, cleaning up, reconstruction, and definition of the needs of the population. The re-establishment of infrastructure was related particularly to electricity (fully re-established at the beginning of October), telephone links, fresh water supply (the ground water table had been polluted by hydrocarbon spills), sewer control, domestic heating, and control of food supplies. The reconstruction phase lasted between 4 and 12 months.

Overview and Consequences (Zimmermann and Müller 1994)

After a week of coordination, the activities of the fire brigades were significantly reduced and were replaced by the military. Fire brigades are typically operational for short periods of time only. The army was instrumental in coordinating work, as opposed to the civil defense where the hierarchy was poorly defined and whose equipment was rudimentary and insufficient. The army was thus perceived as one of the most competent partner in the crisis division. Following the catastrophe, the army remained active for 30 days with aver 1,500 troops engaged. The image of the army within the ranks of the population was boosted during the cleaning up operations. However, the inhabitants of Brig were more reluctant to see the security measures and ID checks established by the military in conjunction with the local police to avoid acts of plunder and vandalism.

After 10 days, the crisis unit reduced its activities, following the cleaning up of rock and mud deposits in the streets and the stepping down of part of the military troops. The members of the unit were partially relieved of their responsibilities when reconstruction work began to be coordinated by specialists of aid organizations.

The crisis management of this catastrophe highlighted the essential role of the Brig authorities, as well as that of the police and local fire brigades, and later that of the army. These key players were first to be on the site during the acute crisis phase, in the first 6 - 36 hours, and then were operational for the immediate management of the catastrophe. Throughout this crisis, the cantonal and federal authorities were not present in the first hours following the catastrophe, even though they had been alerted of the imminent danger in Brig (reconnaissance by helicopter, telephone calls, etc.). It took more than 24 hours to set up an information unit at the cantonal level.
Following this catastrophe, emergency exercises have been conducted by the local authorities. Additionally, technical measures to avoid future flooding by the Saltina have been suggested by ETH-Zurich, involving protective dikes, cleaning-up of the river bed, and predicting zones of alluvial depositing. The previous flooding episode took place in 1927. However, in September 1994, exactly one year after the catastrophe, a small flood by the Saltina threatened Brig once again as a result of a similar meteorological situation. The fears of the town's inhabitants concerning their future seemed justified.

CONCLUSIONS

On the basis of the final report of the NRP 31, which will published in 1997, recommendations for pratical applications, strategies and action plans, will be made for both state institutions and private individuals. Follow-on projects will also be formulated. Although we cannot act to control climate phenomena directly, we do have the possibility of reducing the consequences of natural disasters through appropriate preventive measures. In future, we shall increasingly be faced with problems of catastrophic impacts on natural and socio-economic systems, especially if an increase in frequency and intensity of meteorological «trigger» events, such as those that have affected the town of Brig, are to be expected as a result of global warming. The recurrence of such disasters (when and where the next one will occur ?) and the ability of policy makers to react, represent one significant goal of the research in the NRP 31.

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DISASTER PREPAREDNESS PLANNING AND STUDIES

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ABSTRACT

This paper provides a brief overview of a United States Department of Defense (DoD) initiative to enhance Military Support to Civilian Authorities (MSCA). This project was sponsored by the Space and Strategic Defense Command (USASSDC) under the guidance of Mr. Max Alston, DoD. The targeted user group was the emergency operations centers at U.S. military installations. Our mission was to evaluate current products and technologies and assess their potential in enhancing the capability of U.S. military installations to provide MSCA for All-Hazards disasters. Our team implemented a systems approach to integrating the many commercial and government off-the-shelf products and services which are available to enhance disaster preparedness, emergency response, and reduce human suffering at both a national and international level. We concurrently employed a product oriented approach focused on providing interoperable, user oriented products, not producing another study or developing a new software package. Our products demonstrate the integration of today's technologies and capabilities.

INTRODUCTION

"The views, opinions and/or findings contained in this presentation are those of the author(s) and should not be construed as an official United States or Department of the Army position, or decision, unless so designated by other official documentation".

Our ability to successfully complete a systems approach to producing an Integrated Disaster Preparedness Package and enhancing installation capabilities to interoperate with their communities was due mostly to the selfless cooperation, contributions, and enthusiasm of installations; county, parish, and state emergency management agencies; Director of Military Support (DOMS), United States Army Forces Command (USAFORSCOM), Continental Armies (CONUSAs), many Disaster Coordinating Officers (DCO) and EPLOs; Federal Emergency Management Agency (FEMA), United States Geological Survey (USGS), and the many offices of the United States Army Corps of Engineers (USACE).

PROGRAM OVERVIEW

The USASSDC objectives were to support disaster preparedness planning and study technologies and activities which enhance DoD installation disaster preparedness, and which improve planning for disaster relief relating to DoD installations and cooperative planning with local and international civil authorities. Program requirements included:

- Perform research and recommend enhancements for providing MSCA.
- Conduct site visits to determine requirements.
- Conduct special studies for the National Guard, U.S. Atlantic Command (USACOM), Department of Defense Resource Data Base (DODRDB.
- Produce a legal data base on CD-ROM.
- Enhance interfaces between installation and the civilian community.
- Finally, make determinations on what should be done in outlying years.
- Co-develop an international radiological gaming demonstration.

A general program overview is available on request. The general program overview is a concise pictorial representation of how Program Management maintained a product-oriented, first-year effort. Management utilized concurrent engineering principles to ensure proper integration and to keep each product on schedule and fully coordinated with current and future user requirements.

SCOPE

A general product description from our Integrated Disaster Planning (IDP) Program Package is also available which depicts the USASSDC disaster preparedness planning and study program flow from initial requirements collection and definition to the development and fielding of the IDP Package and the completion and documentation of field exercises. Also documented are lessons learned from actual disaster support; and the final program report to DoD and Congress. As can be seen by the study program flow, this one-year effort focused on the installation and their related requirements for self-recovery and MSCA during all-hazards response. This package and its products are not just for federal or national level disasters. It includes the information and spatial data necessary for the installation Emergency Operation Center (EOC) to also perform day-to-day emergency and preparedness planning activities. In general terms, DoD defined this effort as a bottoms-up study effort. The product which we will demonstrate today is the Installation and Vicinity Data Base.

PRODUCT VALIDATION

The design of this spatial data base and its utility for DoD emergency management and installation EOCs use during All-Hazards emergencies was validated and tested during development by participation in scheduled exercises and actual disaster response.

The USASSDC Program Team rapidly set up a base of operations and fielded four quick response teams during the Southeast Floods of July 1994. The products in greatest demand utilized data layers from the installation and vicinity data base fused together with current weather, imagery, and operational information. The data layers from many different and diverse sources were built using current Geographic Information System technologies and innovative techniques which minimized data loss. The products included visual situation and damage assessments, near real-time imagery and photography integrated with decision aids, population demographics, and evacuation and logistics routing maps.

On-site direct support was also provided to assist the Director of Military Support (DOMS) at the Pentagon; the Alabama, Georgia, and Florida National Guards; the National Guard Bureau; and the National Centers for Disease Control and Prevention.

Testing and validation also included several large-scale hurricane and earthquake exercises including the Joint Warrior Interoperability Demonstration (JWID), Hurricane Polly, and a Central U.S. earthquake exercise with Fort Campbell, KY. The program team also developed and conducted a major radiological disaster exercise in Romania, which was hosted jointly by Romania and Bulgaria. Twenty-two countries attended and actively participated in this international event.

All emergency management data sets and capabilities contained in the Installation and Vicinity Spatial Data Base provide an initial approach to enhancing disaster preparedness. There is still much to be done in the future to mitigate destruction and human suffering. The USASSDC, as a center of technical expertise, stands ready to play a continuing role.

FLOOD SUPPORT

The USASSDC Program Team prepared slide situational assessment and planning documents in support of MSCA agents while planning national level MSCA support during the Southeast Floods of July 1994. The top-level MSCA agent desired to see, on a single graphic, the hydrography of each of six major river systems as flood waters were rising. On this same graphic, they required key cities and military installations which either might be affected or which might be needed to assist should the flooding worsen. Our spatial data base design allowed us to quickly change viewing of the hydrology data to show the Southeastern Flood area with the specific hydrology enhanced. Examples of our spatial database and product samples are available upon request.

Our government-contractor team also deployed quick response teams to support state level flood response planning. The team provided maps depicting requested state and county level situational assessments and planning aids for Decatur and Seminole Counties in Georgia during the Southeast Floods of July 1994. The request was for a single planning tool which would depict the area(s) flooded should the waters be at various flood stages. The normal water level (hydrography) and outline of the Flint River were shown in conjunction with the area and roads which would be covered when the water level rises.

INSTALLATION AND VICINITY DATA BASE

The installation and vicinity data base design focused on producing usable products at the installation EOC for their related requirements for self-recovery and MSCA during preparedness planning and all-hazards response. As such, this data base design is not just for federalized disasters. At the request of installation EOCs, it also includes the design for the spatial data necessary for the day-to-day emergency and preparedness planning activities.

The installation and vicinity data base provide standardized digital spatial data and associated attributes for the production of digital and hard-copy maps in a format and scale consistent with the level of automation at each respective installation EOC. The data base was delivered to each installation EOC free of cost and any licensing or distribution constraints.

INTEGRATION OF KEY SPATIAL INFORMATION TECHNOLOGIES

Several key off-the-shelf digital spatial information technologies were identified during on-site visits and from surveys completed.

- Geographic Information Systems (GIS)
- Computer Aided Drafting and Design (CADD)
- Emergency Management Software (EMS)
- Global Positioning System (GPS)
- Imaging
- Scanning

REQUIREMENTS IDENTIFIED FROM THE FIELD

Spatial data and information requirements were identified from:

- On-site visits to 38 military installations in CONUS and our territories. An additional 83 installations were sent questionnaires to collect emergency planning data.

- Concurrent visits or interviews with more than 50 communities surrounding the 38 installations.
- Visits and interviews with over 100 other civil and government offices and agencies involved with MSCA.

The following general mission-related requirements which were deemed essential for supporting the installation's response mission:

- Enhance self-recovery operations
- Respond to requirements in the immediate vicinity
- Deploy response forces to remote locations
- Provide logistics support
- Provide related planning and training.
- Meet reporting requirements:
  - ⇒ Warning information (activation of EOC, evacuation of facilities, early dismissal of employees, coordination initiatives)
  - ⇒ Response activities (installation missions, missions from others [number, scope, status], state/local requests, general description of damages and reconnaissance/survey data, initial status of facilities, coordination/liaison activities, personnel status, funds status)
  - ⇒ Recovery activities (mission requests from FEMA, status of FEMA missions, requests for state/local, status of state/local requests, personnel status, contract status, funding status)
  - ⇒ Type of event, e.g., flood (by type), drought, HTW spill, earthquake, hurricane, war, terrorism, water contamination (by cause)
  - ⇒ Economic impact (dollar value of damages, number of people affected, type of area affected).
- Provide Presidential and Dignitary Visit Management:
  - ⇒ Damage surveys, planning route and means of transportation.
  - ⇒ Security activities.
  - ⇒ Change-of-command security activities.
  - ⇒ Crowd control.
  - ⇒ Clean-up.

It was clearly evident from the installation visits that not all installations perform all of the above mission requirements to the same degree. In many cases, they are event specific. Additionally, the installations, the CONUSAs, and all agencies visited stressed key requirements, including continuous data base maintenance, data interoperability, connectivity, and standardization of geographic data bases within the national-level disaster preparedness infrastructure.

One of our most challenging steps was to collect information concerning spatial digital data formats. They had to foremost be available in a timely manner so that we could immediately start scheduling the delivery of products. Secondly, as directed by DoD, the products had to be free of any costs and licensing constraints.

The four-month data collection time schedule allowed time to gather data in its resident format from each source. Almost every data source utilized different data base formats. This project recognizes the value of a standard or at least interoperable spatial data formats. One is needed that will accommodate both government and commercial data fusion for emergency management applications both at a national and international level. Our research found significant duplication of spatial data collection efforts in separate offices and agencies at almost every location visited. USASSDC project will continue to work to support the standardization and interoperability of digital formats for emergency planning.

The installation and other agency coordination trips resulted in numerous and sometimes differing ideas and interests in the installation and vicinity data base. From the ideas collected during these trips, implied requirements were synthesized. These fact-finding trips revealed that the level of automation at installation EOCs ranged from none to fairly sophisticated with map viewing and emergency operations and management software packages with geographically referenced attribute data. The typical source of high resolution installation data--the installation Public Works (PW) or Facility Engineers (FE) office, had complex hard-copy and digital data sets available from a wide range of high end Commercial-Off-The-Shelf (COTS) Software formats. These formats were usually incompatible with those required in the installation EOC. These findings are significant as they help define both a key source of higher resolution data covering the installation, as well as the scope of the effort required to produce diverse and enhanced data sets for the installation EOCs.

The requirement was subsequently defined to establish a single spatial data base to support the IDP Project using the COTS ARC/INFO GIS software which was already on-hand at USASSDC. This requirement significantly minimized project startup time and costs.

Additionally, visits conducted on the representative sample of 38 military bases, revealed that most installation EOCs had little or no automation to view digital data or to manage emergency response activities. Those that did have automation usually required a source agency or contractor with a GIS or CADD capability to prepare the spatial data in certain digital mapping formats in order for their emergency management software to view the spatial data efficiently. Therefore, a data loss problem was identified with creating a single data base due to the many input/output spatial data formats.

This data loss problem is exacerbated when relatively few data layers are used with each layer having many attributes. This is normally the case with the many very high resolution data sets generated by engineers as they compile facility data (which is the primary source of existing installation data). For example, the facility engineers may have one data layer for all buildings or structures on the installation. All uses, owners, names, dimensions, etc., would be accounted for as attributes. This method is efficient and makes sense for engineers; however, this is not how the EOC personnel or many of their COTS emergency management software manipulate and use spatial data sets. Typically, layers which are not as detailed were more usable to the EOC, e.g., certain key buildings such as designated shelters or buildings with weapons and ammunition storage, etc.

All the emergency management software packages identified during the installation visits, all installation plans reviewed or discussed, and the EOCs interviewed have the common need to track and manage specific subsets of general building and resource data. However, the EOCs do not require all of the detailed engineering drawing-level data, as the EOC manages, not directs, emergency response. High resolution, detailed maps and dimensions of buildings may be required for use by the on-scene fire chief, military police, bomb disposal teams, utility crews, etc., who actually respond with their resources. If so, they will already have them on hand or in their information system. According to EOC managers who have automation or have seriously been researching the problem, it is unnecessary and too resource intensive for the EOC to try and maintain the extra detailed data. These extraneous data are simply more information to keep updated, and many EOCs are already understaffed to perform the updates required for their current data.

The surveys, additional research, and installation visits also identified the following All-Hazard Disasters and other events as representative of those required of installation EOC managers for MSCA and installation self-recovery. These may also be initiating events and/or contributing hazards due to material, technical disasters, overt actions, planned events and visits, and any number of possible combinations.

- Severe weather
- Flooding
- Earthquakes, slides
- Volcanic activities
- Oil, chemical spills
- Nuclear spills or melt-downs
- Weapons mishaps
- Plant accidents
- Air, marine accidents
- Transportation mishaps
- Hurricanes, tornadoes
- Crime
- Environmental
- War
- Toxic gas release

- Terrorist actions
- Building fires, collapse
- Riots, disturbances
- Massive disruptions
    - Power
    - Water
    - Communications
    - Food supplies
- Contamination
- Dam failures
- Forest, grass fires
- Dignitary visits (President, Pope, large concerts etc.)
- Demonstrations, and major civic events

The requirement was further defined to interface the digital and hard-copy mapping products with the installation EOC, consistent with their respective level of automation and skills. Additionally, the EOC needs to interface with the surrounding vicinity using compatible maps. The EOC and facility engineers may have maps with Military Grid Reference System coordinates, latitudes and longitudes, or no coordinate system. The vicinity will usually have maps with State Planar and latitudes and longitudes, or no coordinates. Very few of the major commercial emergency management software products reviewed thus far can convert to each of these coordinate systems. However, any high end GIS and most CADD software can convert between these coordinate systems.

Due to the various formats and qualities of source data received, the requirement was also derived to make a distinction between a core set of data sources and others. The core set of data sources are those which are, or are expected to be, used by key disaster management agencies that directly influence DoD participation. These are first and foremost FEMA and the DOMS. These include Census data, interstates, primary roads, flood data, nuclear plants, airports, fault lines, hydrology, and federal, state, and county boundaries.

The list below identifies the emergency management software media formats identified for IDP production at selected installations during this one-year effort.

- Hard copy
- Emergency Information Systems (EIS)
- ARC/INFO

These same format requirements were also identified at the CONUSA and DCO levels, at FEMA offices, and at some vicinity locations.

The installation visits all identified the requirements that any data sets and capabilities provided be:

- Usable on a day-to-day basis for other installation requirements so that all installation offices are working from the same data sets.
- Simple and easy to use for EOC operators.
- Focused on standardization, and interoperability with higher headquarters and vicinities.
- Kept up-to-date.

Many installation EOC personnel also work mobilization issues and training area usage during mobilization and need to minimize the number and use of specialized software and data bases.

The number of spatial data layers are being maximized and the number of attributes on each layer minimized. The rationale is that this minimizes data loss and data base export problems during translation from and to the many data formats and platforms involved. Additionally, time and resource savings are expected.

The team reviewed the list of 83 data layers, and established associated work priorities for the 16 thematic groupings considered for the installation and vicinity data bases during this first year effort. See **Table 4-2.** A more extensive review of feedback from installation EOCs and all MSCA agencies after they have exercised the installation and vicinity data base is recommended in future years.

TABLE 4.-2 THEMATIC GROUPS OF DATA LAYERS

THEME	DATA LAYERS		
Hydrology	FEMA Flood Maps Hydrography Ice (Glaciers)	Wetlands USACE Flood plains Hydrologic Units	Snow Coastal Hydrology
Land Ownership	Federal Land Ownership County Land Ownership	State Land Ownership Private Land Ownership	Cadastral
Utilities	Communications Instrumentation Doppler Radar) Sewer Systems	Fresh Water Systems Fuel Facilities Waste Disposal Sites Electrical Power Grids	Transmission Lines Power Grid) Water/Sewer Treatment Plants
Geology	Surface Geology	Elevation Contours	Wells
Atmospheric	Climate (Historical) Temperature (Historical)	Weather (Historical) Radiation	
Boundaries	Installation Census Geography County International	Local Government State Administrative Federal Administrative	Facility Leased Lands Restricted Areas
Socioeconomic	Demographics (Population) Economic	Natality Demographics (Ethnic)	Mortality
Geodetic	USGS Control Points		
Geophysics	Magnetics	Gravity	Seismic
Hazards/ Environmental	Hazardous/Toxic/ Radioactive Wastes Remedial Activities	Medical Wastes Material Safety Data Sheets	Air Pollution Hazardous Materials
Man-Made Features and Structures	Nuclear Plants Fire Departments Base/Unit EOCs Roads Maritime Ports Bridges	Fire Hydrants Man-Made Structures Hospitals Police Departments Designated Shelters Airports	Pipelines Railroads Power Plants Man-Hole Covers
Photogrammetric	Photos and Imagery		
Cultural Resources	Historical Standing Sites Native American Sites	Historical Maritime Sites	Prehistoric, Archaeological Sites
Land Use/Land Cover (LULC)	Land Cover	Land Use	
Emergency Planning Enhancements	Evacuation Routes	Disabled	Troop Support Agency
Subsurface	Bathymetry	Soils	Minerals

Emergency Planning Enhancements were defined as information that provides value-added capabilities for the installation EOC's self-recovery missions and MSCA-related missions. The installation and vicinity data base was designed to eventually contain enhancements that are essential for emergency response. Enhancements will be implemented as time and resources permit. They may appear as data layers or attributes in the installation and vicinity spatial data base, or special map augmentations, such as color coding and symbols.

Enhancements which have been identified for consideration and evaluation include:

- Evacuation routes. Primary and secondary routes identified by disaster type.
- Troop Support Agency (emergency food supply) location.
- Locations of concentrations of disabled and elderly persons.

- Low-lying flood-prone areas next to bodies of water. These areas are prone to flood, but are not identified on regular maps.
- Symbology. Using special symbology on a map to identify important buildings, locations, information, etc.

  Special emergency operation equipment (location and point of contact). Equipment includes jaws of life, chain saws, cutting torches, welding equipment, come-a-longs, shovels (including snow), rakes, Reverse Osmosis, Purification Units (ROPUs), cargo trucks, wreckers, petroleum, oil, and lubricants (POL) trucks, extra ambulances, and helicopters.
- Special emergency operation crews. Operators and crews for search and rescue, fire fighting, Emergency Ordnance Disposal (EOD), bus drivers, helicopter pilots, truck drivers, POL handlers, generator operators, ROPU operators, and mechanics.

The following recommendations are made for future enhancements:

- Maintain in-depth evaluations of off-the-shelf data services.
- Maintain updated evaluations of off-the-shelf spatial analysis and viewing software.
- Perform a long-range analysis of hard-copy mapping scale requirements.
- Define spatial data requirements for emergency management and MSCA agents above DoD installation level.
- Finish populating the installation and vicinity data base with all data layers required by DoD installation EOCs.
- Produce emergency planning enhancements for the installation and vicinity data base.
- Further assess the utility of the Albers equal area and other projections.
- Define additional themes for selected regions and special disaster threats.

CONCLUSION

All emergency management products, data sets, and capabilities contained in the installation and vicinity data base provide an initial approach to enhancing disaster preparedness for military installations. There is still much to be done in the future to mitigate destruction and human suffering. The USASSDC as a center for technological expertise stands ready to play a continuing role. This project was funded through October 1994. However, several initiatives have been funded to include an innovative technology exchange with more than eleven countries under "Partnership for Peace" initiatives. We look forward to participating in other additional national and international emergency planning activities.

BIBLIOGRAPHIES

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SUMMARY: Mr. Roberts is currently employed by Science Applications International Corporation in Huntsville, Alabama. Hands-on experience providing national level quick emergency response, disaster relief planning, spatial analyses, terrain modeling, and data base management using state-of-the-art Geographic Information System (GIS), emergency management software, and imagery analysis technologies. He is proficient conducting weapons system performance evaluations and analyses; developing and fielding Standard Army Management Information Systems; determining manpower and materiel requirements for systems in Integrated Logistics Support (ILS) analyses, material acquisition, and Force Structure Development processes. His systems integration experience includes modeling and simulation, environmental impacts and assessments, integrated system performance testing for national defense and force modernization systems. Mr. Roberts has on-the-ground military experience conducting total system fielding, logistics, and operations on the M109 family of 155mm Howitzers, M107 175mm gun, and PERSHING 1a missile systems for the U.S Army and foreign countries.

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THE ROLE OF STRATEGIC PLANNING IN EMERGENCY MANAGEMENT

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Strategic Planning, Natural Disasters, Emergency Management.

ABSTRACT

Rapid technology development, competition for resources, and an increasing awareness of the global community are but a few of the many forces and trends affecting today's Emergency Management Organizations. The key to success for Emergency Management Organizations involves making the right decisions on important issues such as how best to coordinate between agencies, determining the proper mix and application of technology, and identifying and obtaining the necessary posture to mitigate the effect of emergencies *before* they happen. The identification and implementation of alternatives providing the most effective solutions at the lowest cost will continue to directly influence the level of impact made by both current and future Emergency Management Organizations.

Implementing a continuous Strategic Planning process helps an Emergency Management Organization to formulate responses to issues such as those stated above. By continuously monitoring the forces and trends in its environment, the organization is able to succinctly identify its strategic issues and subsequently frame an appropriate infrastructure of goals, objectives, and strategies. The results on the operations of the organization are often substantial -- including clarification of mission and values, improved horizontal communications and coordination, better resource prioritization and allocation, and the reversal of organizational positioning from a "reactive" to a "proactive" stance.

Strategic Planning also holds significant potential for the emergency management community at large. The wide range of expertise and the inherent dependencies between Emergency Management Organizations at all levels of government -- including the local, national, and international arenas -- makes the emergency management community an ideal candidate to capitalize on the benefits resulting from joint strategic planning. The identification of common issues, priorities, and requirements provides the foundation for increased resource and information sharing, as well as the formulation of strategic partnerships between organizations to battle common threats.

INTRODUCTION

Before, during, and after the onset of a disaster, Emergency Management Organizations (EMO) share a common mission -- to save lives, ease human suffering, and facilitate the restoration of social order and the community infrastructure. Effectively accomplishing this mission is an exercise in teamwork requiring the resources, capabilities, and skills of a myriad of organizations. Working together, these organizations provide not only the power of local and national governments, but also the specialized abilities of educational institutions and industry. In effect, these organizations collectively form an EMO community which rallies around a common mission.

The purpose of this paper is to illustrate the value of strategic planning in facilitating and enhancing teamwork within the EMO community. It is expected that through cooperative efforts the EMO community will realize increased effectiveness in accomplishment of its common mission. This premise is built upon the following suppositions:

1) EMOs share a common strategic mission.
2) EMOs must respond as a team to accomplish this mission.
3) EMOs must respond to many common issues.
4) Increased coordination and communication enhance team performance.
5) Proactive efforts contribute significantly to the mitigation of disaster effects.

By its very nature, strategic planning is forward looking. It is intended to improve organizational effectiveness by providing common direction based on mission understanding and environmental awareness. Strategic planning identifies a set of planning elements such as organizational goals, objectives, and strategies. Therefore, embracing the suppositions presented above, strategic planning is applicable not only to individual EMOs but also the EMO community at large. Figure 1 presents a strategic planning process adapted for that EMO community.

COMMON FACTORS

Mission

A strategic mission can be thought of as an organization's reason for existence -- that is to say, the "identifiable social or political needs that the organization seeks to fulfill" (Bryson 1988). Like its individual organizations, the EMO community shares a "common interest in the mitigation of human suffering and death caused by a disaster, a far stronger bond than any created by administrative means" (Sullivan 1994).

The common mission of the EMO community knows no boundaries -- because disasters know no boundaries.

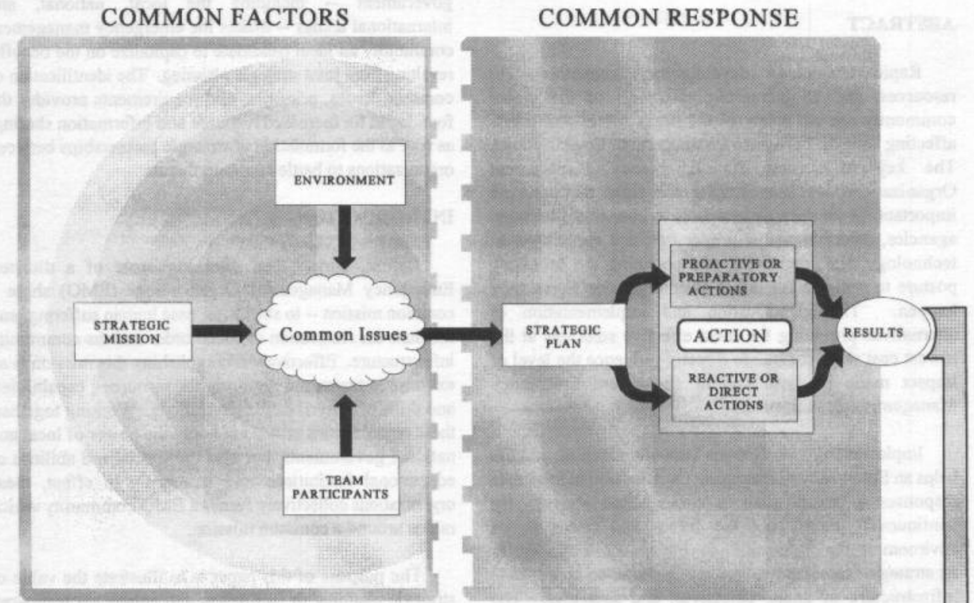

Figure 1 - Strategic Planning Process

Often disaster assistance comes from abroad during a time of need. When the Columbian volcano Nevado del Ruiz erupted on November 13, 1985 it caused a mud slide that virtually buried the city of Armero and claimed the lives of over 23,000 people. To provide disaster relief, workers from a dozen countries worked together in an international effort to support the stricken community -- including a mobile surgical team from Mexico, itself having just suffered the effects of a devastating earthquake in Mexico City only two months before (McDowell 1986). In the United States, disaster relief transcends state sovereignty. When a State Governor declares a state of emergency and calls for Federal assistance, the Federal Emergency Management Agency (FEMA), assisted by numerous other public and private organizations, "mobilizes resources and conducts activities to augment state and local response efforts" (FEMA 1992) to save lives, protect public health, safety, and property.

Participants

The teamwork required to accomplish the common mission involves a number of participating organizations. For example, the National Institute For Urban Search and Rescue lists 80 members on the Advisory Council for their Vision 2000 project -- an effort focusing on the need for comprehensive emergency mitigation and management (NI/USR 1994). From a strategic planning standpoint, participating EMO organizations can be viewed as mutual stakeholders. Stakeholders are "any person, group, or organization that can place a claim on an organization's attention, resources, or output, or is affected by that output" (Bryson 1988). Due to their inherent dependencies with one another to fulfill the mission, the participants that comprise the EMO community are stakeholders because they have a vested interest in one another's capabilities and performance.

Within the strategic planning process, the Stakeholder Analysis is used to help participating organizations understand what they need from one another. During the Stakeholder Analysis information is collected from each of the stakeholders, including:

- Unique or specialized capabilities and assets available to battle emergencies
- Specific requirements and needs necessary to enhance effectiveness
- Criteria for judging success and evaluation of performance against that criteria
- Respective stake in the collective community
- Influence on the community.

Because each organization operates under its own mandates, policy, and procedures, the Stakeholder Analysis helps the collective EMO community to clearly define roles and responsibilities for each of the participants and determine the optimum use of its collective resources. Identifying and reducing the functional gaps between organizations is the objective of this step in the strategic planning process.

Environment

All organizations exist within a greater environment which generates factors that significantly impact the organization. All environments are in a continuous state of change. Understanding the state of change enables an organization to identify threats and opportunities in advance, and respond accordingly, rather than scrambling in response to sudden or unexpected events. Environmental factors take several forms including:

- **Scientific** - Many disasters are strongly related to scientific data. Consequently, having an understanding of the scientific implications of the natural environment is a critical factor in mitigating the effects of a number of disasters e.g., earthquakes, hurricanes.

- **Technological** - Working in tandem with our ability to understand scientific factors is our collective understanding and application of technological innovations. Remaining abreast of the march of technology enables us to understand how best to collect, analyze, and share timely information in our never ending mission against disaster.

- **Economic** - Economic forces and trends affect a host of factors for EMOs such as their ability to acquire and field resources. The level of economic infrastructure in an affected community and the alternatives available to mitigate disaster effects before, during, and after a disaster emphasize the need for strategic planning.

- **Political** - Political factors influence government decisions and actions at all levels -- alternately embracing and constraining EMO interests.

- **Sociological** - Sociological factors such as cultural norms and demographic composition vary between and within nations -- both geographically and over time. Understanding and responding to these sociological factors is progressively more important to participating EMOs in this increasingly close knit global community.

These environmental factors, referred to through the acronym **STEPS**, represent the continuous strategic planning exercise of monitoring environmental change. Because environmental changes will always impact the EMO community, continuous planning cycles are required to ensure the strategic planning process remains effective.

Strategic Issues

Developing an in-depth understanding of the common mission, continually taking the STEPS necessary to monitor the environment, and clarifying the roles and responsibilities of the participants facilitates the identification of common strategic issues facing the EMO community. Examples of such issues include how best to communicate and coordinate between organizations; determining the proper mix and application of technology, and identifying and obtaining the necessary posture to mitigate the effect of emergencies *before* they happen. The identification and implementation of alternatives providing the most effective solutions at the lowest cost will present a continuous challenge and affect the impact made by EMOs. Additional issues may include how to achieve better resource prioritization and allocation and how best to formulate strategic partnerships between organizations to battle common threats. Developing a good understanding of the common issues facing the EMO community is the first step toward improving team performance, effectiveness, and mission accomplishment.

COMMON RESPONSE

The identification of common strategic issues sets the foundation for the formulation of a common and coordinated response. This response is manifested through three distinct components. First, the Strategic Plan articulates the collective planning elements such as Mission, Vision, Goals, Objectives, and Strategies. The second component is the Action which must result from the plan. The third component is the results which stem from the action and ultimately affect the common factors.

Strategic Plan

The Strategic Plan is the collective voice of the EMO community, stating its mission and values, future goals and objectives, and the strategies necessary to turn the goals into a reality. The Strategic Plan is developed in response to the common issues, and as such, it aims to improve coordination and communications, optimize resource prioritization and allocation, and support information sharing. These efforts can be thought of as targeting a breakdown in the functional towers of the community i.e., increasing horizontal, or cross-organizational effectiveness. Correctly developed, the Strategic Plan reflects the consensus of all participants on the best way to collectively plan for, and respond to, the threat of disasters and emergencies. The Strategic Plan leverages the relative skills and capabilities of the members for optimum performance and becomes the springboard for action.

Action

The Strategic Plan must result in actions to provide benefit to the EMO community. Action manifests itself in two forms in the emergency management arena - proactive or "preparatory action" and reactive or "direct action".

Preparatory action includes those efforts undertaken to mitigate the effects of a disaster before the occurrence of the event. Preventive measures such as special construction requirements for buildings located near a fault exemplify preparatory action. Other examples include formal education, inter-organizational exercises, training of all forms, and contingency planning. Additionally, collection, analysis, and dissemination of relevant information concerning subjects such as high risk regions, estimated resource requirements, and state of readiness are indicative of the types of effort involved with preparatory action.

Reactive or "direct action" is the activity which occurs at the time an emergency occurs. Examples of direct action include the deployment and fielding of emergency management units, implementation of evacuation procedures, and the establishment of a Disaster Field Office. Additionally, direct action includes activities such as movement of emergency supplies and mass care of the affected population -- sheltering, feeding, and emergency first aid activities. Repairing damage to roads, airports, and communications systems are further instances of direct action activities.

Results

Actions must yield favorable results for the strategic planning process to benefit the community i.e., fulfill the mission of saving lives, easing human suffering, and restoring social order and community infrastructure.

To illustrate a potential benefit resulting from strategic planning, a conceptual example is presented in Figure 2. This example is based on the notion that Proactive or "Preparatory Action" plays a significant role in the mitigation of disaster effects.

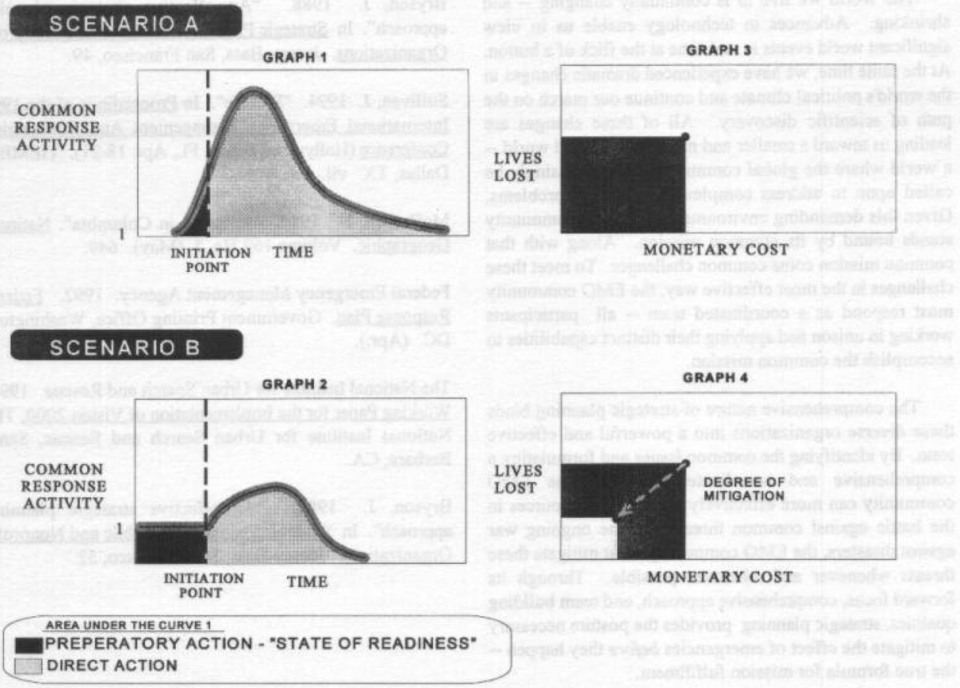

Figure 2 - Potential Benefits

In Scenario A, little or no investment is made in preparatory action, with the majority of the common response activity occurring through direct action. Because the EMO community is responding in a "reactive" mode, more response activity and resources are required over a longer period of time to restore the community infrastructure.

In Scenario B, an investment is made in preparatory action, resulting in an increased "state of readiness". The payoff for the investment in preparatory action is realized through a relatively decreased level of direct activity once the disaster occurs. Direct activity is reduced because less physical damage is incurred due to preventative measures and because the direct response is enhanced through improved coordination and resource allocation and enhanced capabilities e.g., technology and skills sets. Additionally, direct activity is required for a shorter period -- improving the overall team performance of the EMO community.

In Graphs 3 and 4 disaster mitigation is measured in lives lost and monetary cost. Note that Graph 4 depicts a lower level of lives and dollars lost resulting from the investment in preparatory action. The reduction in these factors is indicative of the "degree of mitigation" achieved through preparatory action.

The appropriate types and levels of preparatory action necessary to battle each threat is determined through the strategic planning process undertaken by the EMO community. Additionally, it is suggested that the costs associated with sustaining the preparatory action are shared by the EMO community and other appropriate entities.

CONCLUSION

The world we live in is continually changing -- and shrinking. Advances in technology enable us to view significant world events in real-time at the flick of a button. At the same time, we have experienced dramatic changes in the world's political climate and continue our march on the path of scientific discovery. All of these changes are leading us toward a smaller and more complicated world -- a world where the global community will increasingly be called upon to address complex and difficult problems. Given this demanding environment, the EMO community stands bound by its common mission. Along with that common mission come common challenges. To meet these challenges in the most effective way, the EMO community must respond as a coordinated team -- all participants working in unison and applying their distinct capabilities to accomplish the common mission.

The comprehensive nature of strategic planning binds these diverse organizations into a powerful and effective team. By identifying the common issues and formulating a comprehensive and coordinated response, the EMO community can more effectively leverage its resources in the battle against common threats. In the ongoing war against disasters, the EMO community must mitigate these threats whenever and wherever possible. Through its forward focus, comprehensive approach, and team building qualities, strategic planning provides the posture necessary to mitigate the effect of emergencies *before* they happen -- the true formula for mission fulfillment.

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TIEMEC '95

Management Issues in Emergencies

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SUPPORTING EFFECTIVE DECISION-MAKING THROUGHOUT THE EMERGENCY MANAGEMENT PROCESS

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Keywords: decision-making, integrated emergency management system, comprehensive emergency management

ABSTRACT

This paper describes an effective Integrated Emergency Management System (IEMS) for developing Emergency Management Plans (EMP) which best express a community's commitment to managing hazards and the effects of disaster. It also describes, in general terms, how communities manage disaster response and how the decision-making process should be described in EMPs.

AN INTEGRATED EMERGENCY MANAGEMENT SYSTEM

All governments recognize their fundamental responsibility for public safety.

The mission of emergency management agencies (EMA) is to improve public safety by enabling individuals, groups and communities to effectively manage hazards and the effects of disaster. EMAs enable development and implementation of Emergency Management Plans (EMP) through an Integrated Emergency Management System (IEMS), the most credible, responsible and effective method of achieving Comprehensive Emergency Management (CEM). {Peña, 1994}

IEMS is based on several principles:

People are affected by crisis as individuals, as members of groups and as citizens in communities.

Individuals, groups and communities <u>can</u> act before disaster strikes to prevent or minimize impact, and to assure the most effective response to and recovery from disaster. The extent to which they <u>do</u> act depends in large part upon perceptions of risk before, and event-generated need after, disaster.

How well people manage hazards and the effects of disaster at all three levels (individual, group and community) depends in part on how thoroughly activities are integrated. EMAs must assure high-level integration of emergency management activities.

Emergency management professionals are duty-bound to do the very best job they can. All EMAs are small parts of the governments to which they belong; except during the community's disaster response, emergency management will not be a priority government activity.

An essential function of all (nonelected) public servants is to provide the best available information to support effective decision-making.

THE PROCESS

The process starts with a comprehensive planning assessment at two levels - agency and community. Agency assessments provide information about services, number of employees, hours of operation, facilities and so forth. The community assessment provides demographics, geography, etc. Assessments identify potential special circumstances - people, systems or areas that may require increased or special attention during crisis. The assessment also identify essential functions. For an agency this could mean protecting employees and essential systems and the provision of essential services.

For a community, this would mean law enforcement, fire, public works, public health, human services, etc. All of this is combined with an identification and analysis of hazards of particular concern to the community and is compiled and analyzed by the EMA.

Next, EMAs develop DRAFT Emergency Management Plans (EMP). Based on formats developed by the Federal Emergency Management System (FEMA) and incorporating information derived from the assessments, EMAs write plans which describe how the community and its agencies will manage hazards and the effects of disaster through Comprehensive Emergency Management (CEM) activities. *Comprehensive Emergency Management, A Governor's Guide*, a study conducted by the National Governors Association in 1979, argued persuasively that the activities communities can and do engage in to manage hazards and the effects of disaster fall into four categories - mitigation, preparedness, response and recovery, or CEM. The EMPs developed and refined by EMAs through continuing dialogue with communities identify activities in all four phases of CEM that the community is capable of engaging in. Application of the process at the agency (group) and community levels also assures integration of emergency management activities.

Implementing the plan is the last and most important part of the process. Once a community plan has been developed, it is brought before the governing body for review, comment and adoption. Policy makers must understand how the plan was developed, and they must understand its implications, particularly regarding cost. They must have the opportunity to alter the document to the extent they believe necessary and appropriate, given priorities and available resources. **In short, policy makers must be empowered by EMAs and by those who have participated in the process to make the best-informed decisions possible about how the community will manage hazards and the effects of disaster.** This step is critical; without it, plans can neither be completely valid nor completely effective. Once this step is completed, the community can implement a plan that provides the most realistic and best possible expression of how hazards and the effects of disaster can and will be managed.

DECISION-MAKING DURING DISASTER

One of the most important functions of a community EMP is to answer those questions that can be answered before disaster strikes, so that it is not necessary to answer them during disaster response. However, we must acknowledge that disasters will create unique situations that will require unique response decisions to be made. EMPs must therefore describe an effective decision-making process, one that is flexible and based on what really happens during disaster response.

In its most minimal sense, community disaster response will be characterized by these activities:

> Community emergency response personnel will respond to the site(s) to assess disaster effects and to provide services. More than one agency (police, fire, emergency medical services, public works, utilities and so forth) will have major site responsibilities. Interaction is unavoidable; each agency's actions will impact all others.
>
> Other community personnel, from emergency response and other agencies, will proceed to other locations to obtain and make available essential resources.
>
> Still other community personnel will proceed to a centralized location usually near the seat of government (frequently called an Emergency Operations Center or EOC) to compile and exchange information to support emergency response.

Disaster experience has proved that an effective decision-making system recognizes shared responsibilities. EMAs must assure that emergency response personnel at the site jointly decide how to manage multiple emergency needs. They must also assure that personnel at the EOC jointly support site activities, establish priorities among multiple emergency sites and support response activities beyond the scope of site response personnel (e.g. shelter operations, etc.)

The EMP must describe an effective interagency decision-making process. The following example used in EMPs developed by communities in Dane County, Wisconsin is offered for consideration:

> A. During routine activity the established procedures for managing incidents will be used by community agencies. Some events, due to their duration or other factors, may require coordinated incident site management. In those cases, all appropriate agencies will be represented at the Command Post (CP) and

support will be provided through established structures.

B. During disaster events, all agencies will respond in accordance with both their own standing operating procedures (SOP) and the provisions contained herein. If a conflict arises between the two, the provisions set forth herein will govern:

1. The Community Emergency Operations Center (EOC) will be activated. All local agencies with emergency responsibilities will have a representative at the EOC. Other local, mutual aid and support agencies may be asked to send a representative to the EOC.

2. CPs may be established at or near the emergency site(s), depending upon the nature of the event. All agencies responding to the site will be represented at the CP. There will be only one CP established per site.

3. Communications will be established between the EOC and CP(s) in accordance with the provisions set forth in the Communications Annex of this Plan. Communications will also be established with other facilities as appropriate.

4. Management of the incident will be achieved jointly by EOC and CP personnel. The CP(s) will direct site operations with EOC support. Certain functions (coordination of multiple CPs, prioritizing of needs presented by multiple sites, support of shelter operations, joint public information activities, etc.) will be managed by the EOC, including coordination with other EOCs.

This decision-making process is flexible and based on what disaster experience has shown actually happens in communities stricken by disaster. It also establishes a sound structure for joint decision-making which is so essential for coordinated community response to disaster.

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Peña, R.M. 1994 "Reinventing Emergency Management - Back to the Future" *American Society of Professional Emergency Planners Journal*

Ray Peña has been involved with emergency management since early 1985, first as Director of Disaster Services with the Dane County Chapter of the American National Red Cross and, since 1988, as Population Protection Planner with Dane County (Wisconsin, U.S.A.) Emergency Management. He is Chair of Wisconsin-Nicaragua Partners of the Americas Emergency Management Committee. He is married and has three young children.

TECHNOLOGICAL FAILURE AND DISASTER RESPONSE: WHEN THE LIGHTS GO OUT, CAN YOU SEE THE INSTRUCTIONS TO START THE GENERATOR?

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KEYWORDS: disaster management, system failure, appropriate technology

ABSTRACT

Responding to disaster involves a variety of technological devices to collect, store, process and deliver information and assistance. Technology is seen as a means of making disaster response more effective and efficient. However, technology is not 100% reliable. A failure of a key technology can cripple a response effort and make a mockery of the concept of disaster response.

The paper defines what constitutes a key technology in disaster response and summarizes the roles technology fill in the disaster response effort. A preliminary description of the types of technology failures and their impacts is developed. Suggested methods to minimize the impact of technology failures include fault analysis, redundancy, limiting reliance on technology and redefining technological needs. Potential problems with using these methods are identified, as are areas for further research.

I. INTRODUCTION

Technologies are vulnerable to failure. The impact of a failure is more severe if the probability of failure is not considered in the use of a technology.

The use of technology in disaster response should include steps to counter-balance failure through mitigation measures. Mitigating the impact of technological failures on disaster response makes the disaster response effort more effective by minimizing diversions from the main objective -- dealing with the disaster and saving lives.

A common concept is that more, and more advanced, technology makes for better disaster response. This paper is based on a different perspective, that disaster response technology can become an end in and of itself, with the disaster victim forgotten in the glare of shinny new gadgets. The paper assumes that: (1) disaster response technology does not need be complex to be effective, and (2) a critical review of the roles of technology in disaster response will improve the use of technology in dealing with disaster.

The paper is a preliminary attempt to define relationships between the use of technology and the effectiveness of disaster response. The materials presented are intended to serve as a point of departure for work to improve the use of technology in disaster response.

II. TECHNOLOGY AND THE RESPONSE TO DISASTER

In this paper, technology is defined as "the application of knowledge for practical ends (Random House, 1994)." At a basic level, a specific technology is composed of a power source, which, when engaged, initiates a process with a definite outcome. The power source can be mechanical or electrical and the process can be transparent or opaque (i.e., black box).

An operator initiates a technological action in anticipation of a specific outcome. However, the outcome is not always either controlled or what is intended by the operator. The relation between the actual and intended outcome defines the degree of success or failure of a technological action.

A technology requires neither complexity nor elaborate form to be effective. Three levels of technology can be identified: (1) the unit, the smallest functional piece able to accomplish an action, (2) the system, an interdependent grouping of units intended to produce a specific outcome; and (3) the structure, composed of systems which operate with each other directly or indirectly, depending on the user's intended outcome (after Perrow, 1984).

The term *disaster response technology* refers to technology used at some stage of dealing with disaster. A response technology can be developed specifically to deal with disaster problems or, more often, is a common technology adopted for disaster response use.

This review is based on the concept of a "key" technology as one where a failure of the technology to perform as anticipated results in a serious threat to life or well being. A technology used incorrectly or inappropriately, resulting in a threat to life or well being, is considered a key technology. The key nature of a technology can exist at the level of a threat to individual well being or at the level where the technology serves a vital role in the operation of broad efforts to save lives.

Technology fills important roles in disaster preparedness, planning and mitigation. Most often, these uses are within the context of a technology's normal purpose and address no key need vis-a-vis immediate life or well being. The difference between disaster preparedness, planning and mitigation and disaster response is the presumption for the latter that action is necessary within a specific time frame to prevent immediate death or damage.

The exception is where immediate action is intended to mitigate an expected disaster. In this case, mitigation objectives are time defined and the mitigation actions have the same objectives and urgency as a post disaster response effort.
As discussed in an earlier paper (Kelly, 1994), the uses of technology for disaster management are wide and varied. Some technologies are event specific, many have multiple uses (e.g., satellites, computers). Areas in which technology can support the response to disaster include:

* Data collection and analysis
* Communications
* Transportation
* Personal protection
* Infrastructure
* Health care

The greater part of technologies used in disaster response are those immediately available to victims to respond to a disaster. These technologies include engineered structures; capacities that need not be imported to be used in a disaster response; or technologies not normally used for disaster management. The sophistication of these technologies relates to the developmental level of the affected locale (Kelly, 1994).

In responding to a disaster, externally provided technologies are usually intended to fill a perceived gap in local capacities or to provide support for external assistance providers. In filling this latter role imported technologies can be of little direct use to the disaster victims but of key importance to the assistance providers' efforts.

III. TECHNOLOGICAL FAILURES

Technology fails for a variety of reasons, under a variety of conditions and with a variety of impacts. The presumption in this paper is that a technology used in disaster response is either inconsequential (i.e., for appearance's sake) or important. Thus, failures either have no consequences on the delivery of assistance or a negative impact.

Failure occurs when a technology does not perform as anticipated. Technologies are designed to be used for a specific end. Getting an unanticipated result constitutes a technological failure: the user is not in control of the technology.

A generalization is that technologies fail when used in ways for which they were not designed. However, not all technologies fail when used in an unplanned manner, nor do all unanticipated technological performances have negative outcomes. For instance, failure can prevent a technology intended to do damage from accomplishing this objective.

Even when an unanticipated outcome does not contribute to the loss of life, the user must take other actions to recover from the unanticipated results and attain the desired objectives. This decreases the effectiveness of a response by increasing work to be done and draws resources from the basic objectives of saving lives and maintaining well being.

A technology used in a manner for which it was not designed, but with a correctly anticipated outcome, is not a technology failure as the technology is within the control of the operator. These unintended but innovative uses of technology are probably most common in disaster victims' own efforts.

The causes of failure can be divided into those arising from: (1) a physical failure of a technology or (2) a failure to design a technology to take into account an appropriate use or situation. A physical failure can arise from a design problem, from the misuse of a technology or from damage by an external agent. The failure of a technology can be classified under the following headings, expanded from materials in Normal Accidents (Perrow, 1984) and Guidelines for Hazard Evaluation Procedures (Center for Chemical Plant Safety, 1985).

* Component: failure of an element within a stand-alone unit due to design or physical problems relative to the ability of the component to function as intended. Component failure includes situations where a unit suffers physical damage, as failure is caused by the damage to a component of the unit.

* Unit: failure of a stand-alone piece of technology, as when a unit fails to perform as expected (or at all) when no physical damage is experienced, power is available and appropriate operating instructions are provided.

* System: failure of a group of interrelated technologies (i.e., sub-systems), with origins in: (1) the failure of one

unit to function, rendering dependent units inoperative; (2) a unit providing incorrect input into other units, resulting in unanticipated outcomes; and (3) a unit providing incorrect feedback (as opposed to instructions), resulting in the system failing to take or continue an action.

* Interface (non-controlled systems): failure of a system to operate due to the failure of an associated but non-controlled system to perform as anticipated. The difference from a system failure lies in the inability of the user or affected technology to control the associated system and directly prevent or resolve the associated system's failure.

* Inappropriate Use: failure of a unit or system as a result of use not appropriate for the intended outcome or for the circumstances (environment) under which the technology is used. Where used unconventionally with a realistic expectation of outcome, the technology would be used appropriately in an unconventional manner.

* Complexity: failure due to unanticipated interactions of units in the system. This type of failure is expected in complex systems where system integration poses design and operating difficulties. Causal events include: (1) an unintended use of the system; (2) unanticipated inputs (instructions or data); or (3) conflict between instructions originating from different parts of the system.

* Operator: failure due to incorrect actions by an operator, including a failure to provide power. These actions can be intentional or unintentional. Operator failures can have positive impacts, although the assumption is that operator induced failure is a negative event vis-a-vis the disaster management effort. The intentional misuse of a technology (i.e., use for which the technology is not designed, but with a correct expectation of outcome) would not be a technology failure, per se, although it would have a negative effect on the response effort.

IV. MITIGATION OF POTENTIAL TECHNOLOGICAL FAILURES

Several possible approaches to mitigate the impact of technology failures on disaster management efforts are suggested below. A division between approaches to mitigating problems by exercising more control over technology and ones of minimizing problems by limiting the reliance on technology should be recognized.

Realistically, a combination of approaches will be most successful in mitigating technological problems in disaster response efforts. The review of the role of technologies in disaster response, integral to each approach suggested, is probably the most important element in defining ways to deal with technological failures.

A. Fault Analysis

The most evident way to limit technological failures is through an analysis to identify possible faults and define mitigation measures. Several techniques are available to conduct fault analysis (Center for Chemical Plant Safety, 1985). When associated with the scenario approach to developing disaster response systems, fault analysis can play a central role in improving response systems.

Fault analysis faces three significant limitations. First, the analysis must cover all possible technologies to be used in the response effort. This is a major task, given the variety of technologies which can be used in disaster response and the possible variations in the use of technologies dependent on the size of a disaster.

Second, it is difficult for personnel to perform fault analysis about technologies on which they are not specialists. Assembling a group competent to review a major portion of the technologies used in disaster response may be impractical. There may be a tendency to presume some technologies are fault free, a presumption that contradicts the purpose of the analysis.

Third, disaster response requires flexibility and innovation, which are difficult to fully define in advance. Thus, a pre-disaster analysis cannot easily review technologies as they may actually be used. This presents a particular problem with the unconventional use of technology.

The unconventional use of technology poses significant risks of failure. The operator is not, in advance, fully certain of the outcome of the technological action. Until an anticipated outcome occurs, the conventional expectation is that the unconventional use will be a failure. Conducting a comprehensive fault analysis under these conditions may not be practical.

B. Redundancy

The simplest, but possibly most expensive, way to minimize technological failure in disaster response is by creating redundant systems. Logically, to keep costs down only those systems filling key functions would be backed by redundancy.

Three limitations in this approach are evident. First, how much redundancy is enough? The answer may be based more on financial limitations than on an analysis of failure risks and operational requirements, thus limiting the usefulness of redundancy in mitigating failure.

Second, adding redundancy increases a structure's complexity, with the risk of failure then also including the failure of the redundant system. If the same fault exists in both the basic and redundant systems, only an illusion of safety exists. Building redundancy using systems based on different operating methods to produce the same outcome avoids this problem but can significantly increase cost and complexity.

Third, in-depth analysis (i.e., the fault analysis discussed above) is needed to define failure risks, their interrelationships and redundancy requirements. Once the analysis is completed, decisions are made to either upgrade (i.e., remove the fault) or reinforce through redundancy. These actions then need to be reviewed by an analysis of the changed system. The process can become progressively more complex as more and more technology is involved in removing faults and building redundancy.

C. Limiting Reliance on Technology

Another logical approach to avoiding technological failure is to avoid using technology. The reality of operating in a technological world makes it unlikely this approach can be followed. At the same time, an approach of minimizing the reliance on technology could be practical. The concept is not to avoid technology, but to limit the disaster response system's reliance on key technologies.

This approach can be implemented in pre-disaster planning as a process of answering the following questions:

* What is the purpose of the technology? If the technology does not address an immediate life saving need, then it is probable the technology does not fill a key need. When this technology fails, damage to the response effort will occur only if an operator thinks the technological action is necessary and diverts attention to a failure of no importance.

* Can I do without this technology? Part of answering this question involves defining what is a key technology; part requires identifying the string of systems which must operate for a key technology structure to be successful. Technologies which are not critical to the response process need not be discarded, but their failure should not be treated as significant events.

* What do I do if I have to do without this technology? Answering this question meets three needs for an effective disaster response: (1) developing alternate methods to respond despite a technological failure; (2) identifying redundancy priorities (for those few technologies which cannot be done without); and (3) verifying what are key response technologies (as a confirmation to the first question).

The major problems in limiting technological reliance lie in the pervasiveness of technology in daily life and the common perception that more is better. Performing an intensive review of a disaster response structure is time consuming, particularly if it needs to be done regularly to keep pace with changing response plans and new technologies.

Efforts to explicitly limit reliance on technology will run into problems with those who feel technology can be made fail safe or that technological fixes can minimize the risk of failure. Dealing with these objections can be more taxing and complex than defining what technologies are key to a response effort.

D. Redefine Technological Needs

A fourth approach is to rethink the basic approach to disaster response. The new focus would be on identifying the uses of technologies by disaster victims in their own recovery efforts. The assumption is that victims provide most of the response to a disaster and will use the most appropriate and dependable technologies available. External assistance would support the technologies being used by the victims, rather than trying to lead the response process. Once defined, the victim uses of technology would still need to be subjected to one of the mitigation approaches discussed above.

Two significant problems with this approach are: (1) the difficulties of identifying in advance how a particular group of victims will respond to a disaster, and (2) how to provide supporting technologies while providing training and materials for their use by the victims. Neither problem is insurmountable, particularly for agencies which work at the community level and are able to involve potential victims in the disaster planning and needs assessment process.

For this approach to be successful, procedures for providing assistance need to be flexible and adaptive to the victims' needs. Although straightforward, this process becomes more difficult the further an assistance organization gets from the disaster.

Applying the four methods described above is a progressive process which needs to take into account changes in technologies and response methods. A large disaster response organization should integrate a technology failure mitigation program as a core element of response planning. Smaller organizations should periodically use the reviews of larger organizations to develop mitigation actions.

The prioritization of work to mitigate the risk of technological failure can be accomplished through a two-step assessment of technological structures and component systems. The first step is to define what are key and non-key technological systems. The second step is to rank the key technological systems by direct importance to life saving and welfare. The top ranked technologies become the priorities for risk mitigation assessment.

V. CONCLUSIONS

This paper raises concerns about the danger of an unquestioning dependency on technology for disaster response. Technology is presented as inherently prone to failure, resulting in risks that the failure of a key technology will cause a disaster response effort to collapse. The result could be additional and avoidable loss of life.

Four methods to identify ways to mitigate the risk of technological failure are suggested. No single method will be effective for all risks to all technologies. Using a combination of methods is practical, but should be based on a pragmatic balancing of a need to mitigate risks with keeping the response process as simple as possible. The terminology used in discussing technological failure affecting disaster response is the same as that used in assessing disaster potentials and response options in general. In short, technological failures affecting disaster response are no different from any technological (or non-technological) failure leading to a disaster.

Efforts to deal with technological failure that affect disaster response should follow the same general preparedness, planning and mitigation procedures used to deal with external events, and be an integral part of a comprehensive disaster management system. The priority is to ensure a response organization does not experience a disaster while attempting to assist victims of another disaster.

This paper provides a perspective on technological failure and disaster management as a base for further exploration. Topics for further work include: (1) defining a practical balance between technological fix and minimalist technology approaches to disaster response; (2) developing a catalogue of technological failures and their impacts on disaster response; (3) developing standard procedures for assessing and mitigating risk of technological failure; and (4) formulating criteria to identify circumstances where unconventional or innovative uses of technology will be used in disaster response. Work in these areas will contribute to making disaster management more effective and successful.

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Design of a Decision Support System in Disaster Management

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ABSTRACT

When a disaster occurs, complexity, turbulence and often uncertainty about crucial information and organization make coordination and decisions difficult. Managers faced with emergencies have several ways to take decision :

- from predefined plans associated to identified emergencies,
- from acquired knowledge linking observation to danger evaluation and related startegies,
- instantly, from no experience at all,
- from experience of past disasters and case studies.

Disaster management is complex because each organization has its own regulations, practices and culture, and because managers are not aware of all the knowledge and experience of colleagues from other organizations.

To improve efficiency, organizations such as the International Red Cross are designing and implementing global information systems and databases, to make possible an efficient sharing of information and to make available this experience in disaster management.

This study has been started to propose a decision support system; the goal is to help any disaster manager by exploiting all the experience of disaster management which is available, using Artificial Intelligence techniques to assess similarities between disasters and to benefit from disasters experienced in the past.

INTRODUCTION

Organizations today are looking for ways to obtain systematic information. The globalization of markets has created a need for instant and accurate information available worldwide. This globalization does not exclude crucial information needed in time of disasters. International organizations such as the International Federation of Red Cross and Red Crescent Societies are looking for ways to take an advantageous position in this exchange of world information networks. This last organization is presently putting in place its own telecommunications and information resource facilities in order to take appropriate advantage of this new environment (Federation, 1994). Organizations faced with disasters need tools to exchange and treat information in a more systematic way. The development of decision support systems is a way to complement this approach by improving the use of information.

In a recent research, we demonstrated the importance of communication networks in interorganizational exchanges of resources during disasters (Therrien, 1993). The results of this research showed the difficulties of coordinating and exchanging resources in a turbulent environment for decision makers. Also, some observations led us to believe that the management style of decision makers influences the management of disasters and how decision are made (Therrien, 1994). This paper is a preliminary step for the development of an efficient decision support system that would take into consideration managerial effects of decision makers faced with a disaster.

CONCEPTUAL BACKGROUND

When disasters strike, complexity, turbulence and sometimes uncertainty in the organizational environment make the coordination of the relief effort difficult (Denis, 1993). Decision support systems can now help decision makers manage disasters more efficiently. It can be said that these systems do not always consider uncertainty in the organizational environment. Also, organizations are not always structured with efficient systems that could help the coordination of events.

Efficiency of organizational and interorganizational decision processes in a complex environment could be increased by a decision support system. During disasters, some decisions are made without always considering the effects of these decisions. Also, some decisions are made considering future impacts but one manager cannot always take them all into consideration. It is always after an event that issues of efficiency and effectiveness resurface. Decision makers are often looking for ways to increase their efficiency in the management of disasters. They search for ways to obtain information and means of communication that would make them more efficient in their decision making. But they also take into account past events where they have learned from these experiences.

Decision processes used in the management of a disaster are different from the ones used in "normal" times. Uncertainty in the organizational environment makes the development of proactive strategies difficult. But decision support systems give three alternatives to overcome the limitations of information transactions for decision makers (Comfort, 1993). First, they create networks for exchanges, facilitating communications and focusing their attention on one problem at a time. Secondly, they create a synthetic representation of the information, simplifying the complexity, the speed and exactitude of information. Finally, these systems create more extended data bases of different organizational environments. Vital information of these environments is concentrated, permitting managers to take more informed decisions. These three alternatives give means to managers to reduce their decision making time. In no way could such a system replace managers, or could it increase the efficiency of an organization. These decision support systems give managing methods of organizational problems.

The following description shows the successive development steps of a decision support system that will take into account qualitative managerial data and help transforming it into systematic information to propose decision support.

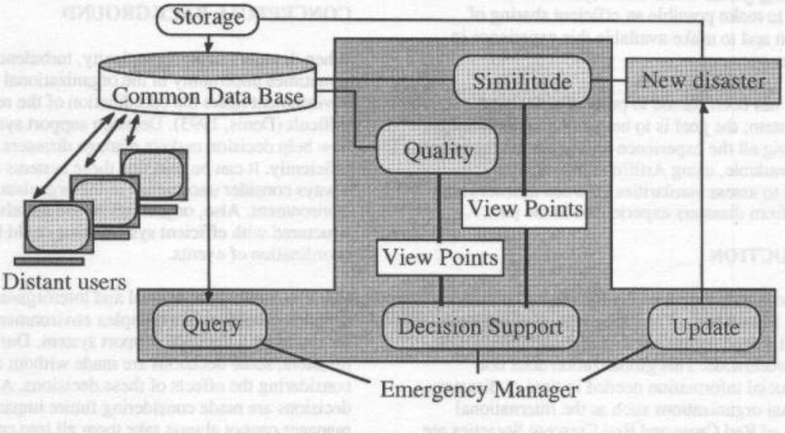
OBJECT OF THIS STUDY

The system we propose to develop will organize the experience in disaster management, by giving access to decision makers to raw information (by a data base) and to a decision support tool that uses this experience in order to be able to face a new event (disaster).

We propose to use an artificial intelligence method, called Case-based Reasoning (CBR). The principle of this method is to build a reasoning based on analogy, which consists in finding problems already solved which are similar to the new one, and to use these solutions to build the solution to the problem (DARPA, 1989; Slade, 1991). Two particular aspects of this method are the definition of similitude and evaluation criteria to assess that a case may be of some interest for the solution. As these criteria may vary, we propose to establish a "view point" approach of similitude and evaluation.

In this application to disaster management, the decision support consists in classifying, according to a similitude criteria and an evaluation criteria, a list of reference disasters that are pertinent to the decisions to be taken in a particular case. These disasters may serve as "positive" references, if they have a good evaluation, or as "negative" ones if they have a bad one.

This study will enable us to structure and formalize case studies by increasing the knowledge we have of problems and of information. It will help to find (according to particular points of view) what can be extracted from acquired experience.



Architecture of the Decision Support System

THE DEVELOPMENT STEPS

The design of such a Decision Support Tool is divided in three steps :
- Analyse the components of disasters and propose a common representation gathering all information which may be useful to assess similarity, to understand the decisions and the flow of events and finally to assess quality or efficiency of the management.
- Design methods and criteria to assess similarity and quality. We propose the concept of points of view, in order to allow any manager to specify what are, for him, similarity and quality. These points of view varying, from one kind of disaster to another, between countries or experts.
- Design a system which allows an efficient access to any data, creation and updating of points of view and easy use of decision support functions.

We have chosen an Artificial Intelligence approach because such a system cannot be definitly designed and propose only a constant behaviour. We think that the manager has to consider the system as his own to trust it: he must be able to decide its functioning and to understand its behaviour. A second reason to choose AI techniques is the constant evolution of techniques and disasters which creates the need for the system to memorize new disasters and to use new experiences as they come up.

The study consists in five integrated phases. The first phase consists in structuring relative information of different disasters by doing case studies. One case study consists of :
- the temporal aspect: a description of the disaster in a time frame (conditions, causes, events, etc.),
- the organizational aspect: a description of the decisions behind the actions done in a time frame (management of the relief effort, organizations implicated, experts, decisions, etc.),
- the causal aspect: a description of the consequences and an evaluation of the disaster and decisions, be they positive or negative (victims, pollution, cost, etc.).

The second phase consists of studying the notion of similitude (according to one or several viewpoints) between the temporal aspects, in order to select relevant cases in the database that are similar to the new disaster.

The third phase will study the notion of quality based on causal aspects of past disasters and criteria that the manager considers for the present one (representing also a view point).

The fourth phase consists in finding methods to help the user to adapt the different cases that are of interest to him (similar cases that managers find of good quality) in order to reuse some elements.

The final phase consists in defining how the user will be able to enter the temporal, organizational and causal aspects of new disasters in a well defined framework, so they can be used for decision support.

CONCLUSION

This research is a reflection on decision support systems in complement to functions of simulation and access to global information. It will bring structuration of relative information of disasters, and will facilitate the gathering and the treatment of this information. It will also permit to study the notion of similitude and the evaluation of disaster management. Finally, this study will validate the use of experience and case studies in decision support for emergency management. This information is often unusable in stress conditions, because of its location which can be far from where it is needed, because of its format or because of its size, which may be too large.

Our approach may constitute an efficient decision support by extracting from this information the only elements which are important for a fast and efficient decision making.

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TIEMEC '95

Management and Planning Issues in Emergencies

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GETTING THE WORD TO THE PEOPLE

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Nearly everyday some part of our Nation is hit by heavy weather. The U.S. National Weather Service (NWS) is involved in a major modernization and associated restructuring program. Experiences with the new technology have exceeded all expectations for the issuance of weather warnings. The lead time for severe weather warnings using the next generation weather radar is up to 30 minutes. At the same time, the U.S. Geological Survey is involved in modernizing the Nations seismic monitoring network.

But, it doesn't matter how good the technology is or how accurate and timely the warnings and forecasts are, if they don't reach all citizens in a timely and understandable manner they have little value. With this in mind, a major goal of these modernization activities is to also improve the Nation's hazard warning system in order to get the word to the people.

Today, we have in place a strong public-private partnership for the dissemination of warnings and other vital information to the public. These include:

NOAA Weather Radio (NWR), the sole government radio system for providing direct warnings of natural disasters to private homes. This life-saving radio network of 380 stations covers all 50 states and is within listening range of 90% of the population. During severe weather and other emergencies, these radios (which can be battery operated) can be automatically activated, so that the warning message is audible, alerting the listener of impending danger.

The NOAA Weather Wire Service (NWWS) is a satellite-based communications delivery service providing forecasts, warnings, advisories, and other data to extend users such as emergency managers, public safety officials, the media and others.

Since 1983, the NWS has operated a family of medium-speed communication services called "The Family of Services" (FOS) which brings near real-time weather and flood data and other hazard information to external users such as the media and private weather information companies.

The Weather Channel, a 24-hour-per-day cable television channel reaches over 60 million homes in the United States, relaying NWS warnings and forecasts and vital information on other natural hazards as well as on preparedness and awareness to its viewers.

Because of their universality, commercial radio and television broadcasts are particularly effective in issuing warnings. Recognizing this potential, the broadcast media have arranged to disseminate NWS severe weather and flood warnings, as well as other natural hazard related information. Meteorologists at most television stations and some radio stations ensure the quality and timeliness of the information disseminated.

The Emergency Broadcast System (EBS) is another vital link in getting warnings to the public. The EBS was originally established in 1964 to provide an efficient way to communicate with the American public in the event of war, threat of war, and grave national crisis. In recent years the EBS has greatly expanded to encompass the state and local levels as well. The system is now activated more than 100 times per month to disseminate natural hazard information to the public. Under a statement of requirement for communications with the general public during periods of national emergency, FEMA and the Federal Communications Commission determine technical arrangements for the establishment of the optium EBS, and the NOAA NWS assists in developing a viable state and local EBS. In the near future, the EBS will be upgraded. This historic upgrade, the first in over 30 years, will be driven by state-of-the-art technology. NWR message encoding and protocol capabilities are being evaluated now for inclusion in the new EBS.

Plans are also underway to enhance the NWR, NWWS and FOS with an "all hazards" capability by incorporating earthquake, volcano, and landslide information provided by the U.S. Geological Survey and post-event information, such as locations of shelters and other emergency services, etc., provided by state and emergency management officials.

But not everyone receives the latest information. Radio and television programming is not always interrupted when emergency messages are released. Some people are sleeping, some could be watching movies on video recorders, others are out of range of the electronic media. Many, such as the infirm and disabled, do not have instant access to warnings.

To overcome this problem, we have set a goal is to place a NWR receiver in every school, hospital, nursing home and day-care center in our country through a partnership with state and local government and the private sector. Just like smoke detectors and other home safety features, NWR should be found in every home. Another goal is to make the NWR frequencies available on all automobile radios.

The benefit is quite obvious...a system which provides instantaneous receipt of natural hazard warnings as well as vital preparedness information, will allow people to take the necessary precautions to safeguard their lives and their homes. During a disaster, NOAA Weather Radio will provide instant contact with anyone who has a receiver.

By heightening the awareness of our citizens to the impacts of natural hazards, they will be able to help themselves. They will make the right decisions and know how to respond when a disaster strikes. NWR is a simple inexpensive device to help accomplish this goal.

INTERNATIONAL KNOWLEDGE BASED SYSTEM FOR EMERGENCY DECISION SUPPORT

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KEYWORDS: decision support systems, knowledge based systems, international collaboration

ABSTRACT

The computerized support of decision-making is a necessary condition of making qualitative decisions during emergency situations when dealing with complicated problems with large amounts of information. Intelligent computer systems with telecommunications and networks used for knowledge accumulation can be efficient tools in this area.

INTRODUCTION

The computer support of decision-making is a necessary tool for emergency situations. To work out decision support systems (DSS) effectively we should develop acquisition technology. As usual emergency events are very seldom in one place. But if it were possible to collect all information about some kinds of emergency issues around the world we could create a more complete knowledge base. So globalization of emergency management and engineering is the main stream of Emergency Decision Support Research and Applications.

To solve this problem it is necessary to develop an international information network for emergency knowledge exchange. There are many computer networks which are possible to be applied to this purpose. A key issue of this direction is the data interchange protocol and systems communication technique. There are some achievements in this field in computer communication networks. But it is necessary to develop a structured, machine–retrievable data format that permits data to be transferred, without transformation, from a decision application in one location to an application in another location.

Another key issue of the task is the finance and organizational problem of such kind of systems development. The key idea of this approach is involvement of an insurance company in this activity. There would be some benefit for an insurance company to develop such kinds of systems. In this case it is possible to decrease the loss from emergency events. An international association created by researchers, users of those systems, and insurance companies is an effective way of solving the finance and organizational problem.

INTELLIGENT METHODS OF DECISION SUPPORT SYSTEMS DESIGN

The computerized support of decision making is a necessary condition of making qualitative decisions when dealing with complicated problems with large amounts of information. Computer systems can be efficient if they are quickly made, well adapted and disposed to the changing conditions and take into consideration some personal features of a decision maker. To work out decision support systems (DSS) effectively we should make and use special program tools: generators, shells, and modern programming technologies. A decision maker will succeed using DSS if the system has intelligent features. These two directions in intelligent DSS design are investigated in this paper.

In view of the announced crisis in programming technologies new approaches to raise programming efficiency are intensively worked out. They include modern programming–mathematical means. Logical, object oriented and functional programming are the modern tools to solve such difficult problems. These tools make it possible to create interactive systems which allow a user to formulate a problem and store knowledge about problem solving methods. Such methods are subdivided into general methods, methods corresponding to the subject matter, methods of handling a concrete problem and methods depending on the decision maker.

Methods of artificial intelligence and, in particular, expert systems arrange these means into a system. Great hopes in this field are given by the usage of CASE technology which is fruitfully used for IS design automation. One of the major directions of future computer systems is integration of artificial intelligence technologies and information systems (Brodie 1988). Future Intelligent Information Systems—AI and knowledge base management systems (KBMS)—are the necessary element of artificial intelligence systems. No industrial samples of KBMS have been recently devised, data base management systems (DBMS) being well developed at the same time. The use of the latest achievements in data base technology allows to use relational DBMS as the first version of KBMS. The use of relational algebra methods makes it possible to formalize operations over the KBMS information, to use inference rules.

COMPUTER SUPPORT

The modern advancement of computer technology and computer science has put forward the task of developing such computer hardware–software systems that would provide the user with appropriate computer support for the whole cycle of information processing, from the collecting of information and knowledge acquisition to decision making. Considerations include:

- the improvement of informational support for computer systems as well as the availability of such support, for almost the whole range of scientific disciplines dealing with the Earth and ecology;
- large amounts of accumulated unprocessed and uninterpreted information;
- the importance of rapid accessibility and efficiency of utilization of corresponding data bases in order to successfully address a wide variety of social, scientific and economic problems; and,
- the existent high level of modern computer hardware and software which allows us to efficiently collect, store, retrieve and process a large knowledge base.

The development of such systems which is presently underway brings about the need for the working out of the basic principles and mechanisms of their functioning as well as for the development of special program modules which would necessarily have to be included in such systems. Among the emerging tasks which will have to be implemented are the following:

- creation of regional centers;
- development of computerized workstations and terminal stations on the PC base to be used by specialists from various fields of knowledge in their work;
- development of problem–oriented mathematical models in parallel with the development of more general techniques for data processing and analysis; and,
- creation of efficient decision making techniques including those which could be applied to cases with insufficient information or to cases with varying reliability levels of information (Britkov 1991a).

Among the major advantages of this approach are openness and the use of advanced man–computer dialogue techniques. Openness implies the possibility of an easy coupling to the System of additional data bases, models and data processing routines. The System's man–computer dialogue interface is oriented towards the use of more advanced devices and facilities for man–computer interaction with a wide exploitation of multimedia methods (Britkov 1992).

INTERNATIONAL KNOWLEDGE BASED SYSTEM FOR EMERGENCY DECISION SUPPORT

According to the conventional methodology (Britkov *et al.* 1980) the first stage of design is subject area modeling. A subject area knowledge base is developed at this stage which can be divided into three parts (Britkov 1991b):

1) general knowledge;
2) specific subject matter knowledge; and
3) research specific task knowledge.

The boundaries between these databases are relative and are determined by the mode of use of proper knowledge (Britkov and Vyasilov 1994). This knowledge is used at the subsequent stages of development using formal and non–formal methods of design (Cauvet 1988). The E–R approach (Chen 1976) has recently been the most popular for subject matter modeling of information systems. Despite its limited nature and drawbacks it is widely used in projecting tasks. A vast score of attempts to develop and generalize the E-R approach have been taken (Gutzwiller 1988), but none of them has reached the stage of being well developed.

According to this methodology it is necessary to develop the special structure of a network and some subnetworks. There are some levels of exchange of experience and knowledge about emergency situations and decision making in these cases. Every subnetwork connects objects of the same kind or the same branch of industry.

There is positive experience between mathematicians and insurance companies collaborating in an actuary society. The international aspects of such activity are very important, because emergency situations may not be very frequent in every country (fortunately). International experience and collaboration will give a good chance for the development of knowledge based emergency decision support systems.

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RISK MANAGEMENT:
ROLE OF SOCIETAL FACTORS IN MAJOR INDUSTRIAL ACCIDENTS

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KEYWORDS: Major accidents, accident causes, societal factors, complex technological systems.

ABSTRACT

The paper discusses factors influencing the occurrence of major accidents in complex technological systems. Societal factors are identified as most significant in this context. Important types of societal factors are pinpointed and discussed. The safety situation in the former Soviet Union and in today's Russia is described. The calamities at Chernobyl, Three Mile Island, and partly also Bhopal are discussed, and the role of societal factors identified. A main point of view is that it is not surprising that these catastrophes happened in the then existing conditions. What is surprising is that they did not happen earlier!

INTRODUCTION

A great number of publications devoted to various aspects of industrial safety and prevention of accidents are available, covering a wide range of different fundamental and applied issues. A distinct and significant tendency may be noticed in this literature; the emphasis is usually put on the immediate and direct causes of serious industrial accidents, i.e. on technological, managerial and operating failures, faulty decisions and actions of personnel, defective designs or constructions, etc. This emphasis is understandable and cannot raise, of course, any objections.

Industrial accidents do, however, not arise in isolation from societal factors. A variety of social factors are strongly affecting the level of safety, and are necessary for industrial systems to function effectively and economically. Changes in the society, especially the introduction of various regulatory mechanisms, and the need to employ educated, qualified personnel with specific abilities for positions of responsibility on hazardous industrial installations are adding new, societal dimensions to safety, transforming it into a multiaspect problem.

Research and numerous accident inquiries show that in an overwhelming majority of cases serious industrial accidents must have other, more concealed and deep-rooted causes than direct engineering and managerial faults, however serious they might be. Regrettably, *indirect* causes of major accidents, that appear to be not connected with safety per se, often remain unidentified. Among them *societal* factors (in the broadest sense of the term) should be named in the first place, as they often play a specific and essential – though not always easily discernable – role in serious industrial accidents.

Powerful factors of social character *in conjunction* with other factors create *preconditions* for any serious industrial accident. In a certain sense all these factors; technological, managerial and societal, acting simultaneously and together, make these accidents in a sense inevitable (not, however, at a definite place or time).

From this point of view serious industrial accidents emerge as complicated socio-technological phenomena characterized by not only the level of technological development and engineering foresight, but also by the specifics of socio-political systems of a particular country, its societal management arrangements and institutional structures, behavior motivations of personnel participating in industrial activities or in some cases of the population living near industrial plants. It seems important to detect all these factors predetermining the accidents before (however strange it could sound) they would happen in reality. These factors are not unique or specific of any country or region. The Chernobyl, Three Mile Island and Bhopal accidents, and in fact any other catastrophes of such a magnitude could happen in any country with a developed industrial base. Thorough analysis of major accidents should – and in many cases does – reveal the interplay of these factors, societal including, and their impact on the general state of safety.

Political, economic, environmental, and also socio–psychological dimensions, social mentality and motivations of various groups of people, even individuals, directly connected with industrial processes per se should be included in the range of these factors.

All this, certainly, does not mean that these factors are fully ignored by analysts, investigators or scientists. Sufficiently wide research has been made to that effect, but to a conspicuous degree it is concentrated on social aspects of the "consequences", that is social impacts of the accidents, what happened *after* them. It seems much more important to detect these factors and take them into consideration *before* they could produce an emergency situation or result in an actual disaster. Analyses of serious industrial accidents should reveal also the deficiences in socio–economic systems, societal mechanisms and methods of social organization and management which in the long run may become instrumental in creating "favourable" conditions for man–made technological accidents.

The experience accumulated so far and the specifics of serious industrial accidents compell to look at the phenomena from a broader point of view, owing to at least two reasons:

(i) In complex technological systems of strictly balanced design, in particular hazardous by the nature of their processes, failures often produce intricate chains of events, leading to unpredictable coincidences of equipment failures, managerial faults or operators' mistakes, defective designs or socio–psycological problems ("human factors") with serious accidents as the end result. The whole array of all these causes might be easily overlooked, as many important data or information could be irrevocably lost in the course of accidents, ignored or even intentionally hidden.

(ii) It is usually meaningless to look for a single *main* cause of a major accident, though for practical, for instance legal purposes, a principal cause is often chosen and accordingly declared.

Our main point is: *societal* factors should be included in the number of probable causes of serious industrial accidents, and their role in making accidents realized or probable defined. This should be understood in the sense that powerful factors of the social dimension, in conjunction with other factors, create general *preconditions* for industrial calamities.

The role of societal factors is especially evident in countries where radical societal changes and upheavals are taking place. This aspect is especially important. The development of appropriate safeguards against accidents should take into account changes and perturbations in the political and economic spheres, and their possible effects on the safety situation in the industrial sector.

Rapidly changing socio–economic conditions in these countries are finding their particular expression in the redistribution of incomes and welfare benefits, of the ownership of large industrial plants, growing economic problems and inflation, rapidly changing political climate, etc., and are usually resulting in new relations in the industrial sphere, and patterns of motivations and behavior of people engaged in industrial activities. Profit considerations, for instance, may produce particularly negative and long–lasting impacts, as entrepreneurs in a rapidly changing economic climate try to ensure extra profits in shortest time, economizing on every possible measure, including safety.

THE SAFETY SITUATION IN RUSSIA

The Soviet Union with its highly centralized, deeply planned, and administratively run socio–economic system had for a long time been suffering serious losses connected with industrial accidents. All the factors mentioned above were acting together and resulted in heavy material and social losses for the Soviet economy. According to several research projects undertaken in Moscow and Kiev, aggregate losses due to industrial failures (excluding the Chernobyl catastrophe) amounted in the 1980s to approximately 15–20 billion roubles per year (in 1986 prices), which roughly corresponded to 20% of the appropriate global losses! The consequences of the Chernobyl catastrophe alone were for the country shattering, but in fact have never been properly and reliably estimated. Different figures have been mentioned, starting with the official 8–11 billion roubles, reaching 200 to 300 billion roubles (in 1986–88 prices) or more, appearing periodically in the press. Nowadays the problem of the assessment has evidently been dropped altogether probably because of the absence of suitable methods to apply to this case and inability to arrive at a realistic and reliable conclusion.

The analyses of developments in the safety sphere in the former Soviet Union and later in the Russian Federation, its prime successor, deserve special attention, as they present both an illustative and instructive picture of the developments in the safety sphere of considerable scientific and applied significance.

The safety situation in the USSR was mainly the result of inability to introduce appropriate and long overdue improvements in the regulatory and other safety mechanisms so that they could correspond to the requirements of the highly developed industry the USSR possessed. For such a situation to emerge there were several important reasons which were specific for the then existing socio–economic conditions in the country:

- The most obvious reason was that the industrial safety problem in the USSR remained practically outside the immediate attention and interest of wide scientific and professional communities until the mid 1980s. Though some scientists of position expressed serious concerns in connection with the safety situation, especially in the nuclear industries, the general pattern had not been changing, lack of any effective research continued, administrative measures were practically non–significant on national level.
- Serious harm had been inflicted by the so–called *"absolute safety"* concept, based on the general premise that protective measures of exclusively technological and managerial character were sufficient to ensure complete safety ("absolute" in their parlance) of complex techno–industrial systems.
- Central industrial ministries had at their disposal considerable economic, administrative and other means to compensate for the losses connected with accidents on subordinate plants, so practically nobody was much interested in gathering and analyzing, more so in disclosing real data about accidents.
- Concentration of all essential data and information concerning industrial accidents in central administrative bodies, especially dealing with nuclear, aerospace or military activities, almost inevitably resulted in the concealment of all data on security grounds with negative effects on the resolution of safety problem on a national level. Absence of aggregate statistical data aggravated the safety situation during that period.
- A rigid system of strict *secrecy*, permeating the USSR industries (military and non–military alike), resulted in artificial barriers for the exchange of safety information and the accumulated experience not only between different branches but even plants. Eventually it became a serious obstacle to technological progress in general, and to safety particular. The corollary was the neglect of *world experience* connected with industrial accidents. This aspect had extremely negative effect on the nuclear industry. The TMI accident data, for instance, that was widely known in the West, got a limited circulation in the Soviet nuclear establishment. The information was generally unavailable to rank–and–file engineers and operators, and other professional groups that should have got direct access to the data. This information might have prevented the numerous cases of blatant disregard of operational instructions and carelessness of operators.

With the beginning of "glasnost" in the 1970s many serious drawbacks in the safety sphere began to appear in scientific publications and mass media. Information about accidents, available earlier only to a narrow circle of high administrators, could now be analyzed by specialists not connected with the administrative apparatus.

The Chernobyl catastrophe demonstrated to all the seriousness of the safety problem and the necessity of radical changes to counter negative tendencies.

In Russia (after the dissolution of the USSR) the safety developments have taken place in different socio–economic and political conditions with different societal forces and basic motivations. Several specific features and data may be singled out (referring mainly to the period 1991–93):

- *Growth* of the number of accidents in the industries and of traumatism projected even on the decreasing industrial activity during that period; (In 1992 the number of fatalities in the industrial sector of economy increased by 17.2% compared to 1991. Transportation of hazardous materials led to 12 serious railway accidents with heavy loss of lives, and a large number of less significant incidents, including more than 800 releases of dangerous or toxic materials. In the mining industry more than 68% of the losses were connected with accidents. Traumatism in open mines increased by 83% In the building materials industry – 2 times).
- *High accident rates* in the industries had been directly connected with negative social developments in the industries. Lowering the level of technological and general discipline on the plants became common and chronic, often connected with such social evils as abuse of alcohol.
- The use of *obsolete* equipment in Russia and the former USSR republics.

(Half of the park of industrial elevators has already far exceeded their maximum lifetime. Replacement of more than 2 000 kms of gas pipelines could not be delayed any more, 10 000 kms require urgent anticorrosion protection measures. A grave situation with gas lines exists in large cities. In the oil and gas processing industries, a significant part of the installations inspected during the last years should be immediately decommissioned or urgently reconstructed).

- The *break* of traditional ties between various branches of economies of the former USSR republics and between plants has resulted in interrupted spare parts deliveries, disrupting maintenance and repair activities and impairing safety stability of the plants.
- In the Soviet Union the legal basis for safety regulation had been essentially the result of administrative activity creating a system of *by–laws* issued by appropriate governmental agencies. The legislative practice in the form of national safety laws in fact was insignificant (mainly concerning standardization). The situation had become a main obstacle to effective accident prevention on a national scale. Incidentally, general safety legislation still has to be created simultaneously with structural changes in Russian economy, a difficult and time–consuming task.

If these and other negative trends are not controlled, the future developments might be troublesome, indeed, with a highly probable further growth of accidents, increasing traumatism and environmental impacts. Naturally, more and more attention is being paid in Russia to change the existing safety situation. Recently there have been some important governmental decisions, relating to state regulatory mechanisms and the organization of fundamental and applied safety research (e.g. the "Safety" state program for 1991–95 or similar state programs for environmental protection and other activities).

A *comparative analysis* of actual major accidents is most appropriate here, relying mainly on the conclusions of various investigative bodies and omitting technological and operational aspects.

THE CHERNOBYL CATASTROPHY

(April 26, 1986)

From a purely technological point of view the Chernobyl accident did not add anything significantly new to the existing knowledge. The accident, however, became a tragic lesson for the country, the results of which, may not have been fully comprehended up to now. Just as an illustration: now, 9 years after the Chernobyl catastrophe, Russian nuclear industry still does not have a developed legislative support for its activity!

The Chernobyl calamity was unique in several other aspects – large masses of population were exposed to considerable radioactive fallout; biological, socio–psychological and ecological effects spread over large territories with repercussions on a continental, if not global level. It happened during a period of general social complacency and was completely unexpected for all – governmental officials, managers, scientists and specialists, not to mention the public at large.

The existing evidence supports a conclusion that it was a clear case of operators' conformism, inability to think independently and make *competent* assessment of the situation with appropriate personal behavior. It was also the expression of technologic illiteracy on the part of managers and the irresponsibility on the part of supervising agencies accustomed to the breach of duties.

An important factor on which the accident shed light was the system of personnel selection. Of course, there is not much guidance on "correct" selection methods, due mainly to the difficulty of defining criteria for successful managers' or operators' performances. But *deficient* systems of personnel choice for responsible managing and operating positions should be emphasized. People with insufficient technical knowledge, work experience or inappropriate personal qualities were appointed to the positions of exceptional importance. The manager and chief engineer of the Chernobyl plant, for instance, appointed according to the then existing procedures, were not nuclear specialists and had no appropriate education. Not surprisingly, they possessed only vague perceptions of the processes in the reactors, which eventually led to the tragic results.

So, this unprecedented man–made calamity was only in part a technologic failure, in its essence it was a case of a gross social failure.

An opinion exists – it is not surprising that the Chernobyl catastrophe happened in the then existing conditions. What is surprising is that it had not happened earlier!

One of the main results of the Chernobyl accident is that the problems of the Russian nuclear industry since then have become almost exclusively of societal character.

THE THREE MILE ISLAND ACCIDENT

(March 28, 1978)

The law suits and the investigations of the TMI–accident disclosed, according to Perrow (1984), a seemingly endless story of incompetence, dishonesty and cover–ups both before, during, and after the accident.

The work of the Kemeny commission acquired a particular significance, revealing the irresponsibility of the utility company (Metropolitan Edison) that had not been managing the nuclear installation properly. There were also cases of cheating on the part of the appropriate company's officials before the accident, and attempts to cover the real safety situation on the plant. It is remarkable that during the qualification tests readministered after the accident, one–third of the licensed operators failed to pass them. The most damaging of all was, however, the fact that inadequate, improper and even criminally punishable procedures had been used for certain leak–rate tests at the TMI unit–2 *prior* to the accident.

The Kemeny Commission noted: "The major factor that turned this incident into a serious one was inappropriate operators' actions, to which many factors contributed, such as deficiencies in their training, lack of clarity in the operating procedures, failure of organizations to learn proper lessons from previous incidents, and deficiencies in the design of the control room .... We are convinced that an accident like Three Mile Island was eventually inevitable".

In the final conclusion the Commission stated that it was the case of cataclysmic human errors that eventually led to the accident.

Again a serious societal failure in conjunction with technological and managerial ones.

Almost the same basic conclusions could be drawn from the analysis of the Bhopal tragedy which, certainly, had specific societal and managerial features as the general conditions were different, in particular the owner of the plant was US–based Union Carbide, a transnational company, running the plant from the United States with the socially complicated situation in India.

CONCLUSIONS

A number of other social factors of significance can be named which could play an important role in safety issues, such as economic factors, general political or economic stability (or rather instability) in a region or a country or the professional or general education level of the workforce, which all affect the motivation or the behavior of people in the course of industrial activity, their attitude to their functions and to safety requirements.

A wide range of effective societal instruments is now at the disposal of specialists, which could considerably increase the industrial and environmental safety, if applied effectively and diligently. Among the measures of this kind are:

- Development of effective regulatory and legal bases for safe and effective operation of complex techno–industrial systems. World experience has proved that the existence of developed safety regulatory mechanisms is one of the prime prerequisites for effective prevention of industrial accidents.
- Effective participation of the public in the resolution of safety issues, in particular connected with the construction of hazardous industrial installations in areas where the public interests or rights could be affected.
- Wide use of methodologies developed by national and international research institutions with the purpose to raise general safety level of the technologic processes and the security of the population and the environment; the creation of the international specialized data banks on accidents and preventive measures.
- Growing importance of international activity in the prevention of serious industrial accidents, minimization and localization of harmful conseuences should also be stressed. Interconnections and interactions between nations in the safety sphere are now acquiring such a focus that the formalization and internationalization of safety regulation procedures and standards, and elements of compulsory enforcement of certain agreed actions is now on the agenda of diplomatic activity.
- Construction of industrial systems which could correct wrong decisions or actions of personnel, in particular systems with intrinsic safety features (e.g. nuclear reactors);
- Introduction – wherever possible – of licencing mechanisms with participation of the public and open hearings for hazardous industrial installations and independent administrative control of their performances;
- Introduction of the system of "proofs" to provide evidences that a candidate for a particular

responsible position on an industrial installation with high risk of accident or hazards possess necessary abilities and qualification to be accepted. The lists of such positions should be adopted by appropriate legislative acts.

The pace of technologic change and growing scale of industrial activities is now so great that to rely on conventional evolutionary "trial and error" approach to achieve optimal decisions becomes unproductive. Now it is necessary to forsee the problems which could arise in the course of operation of a plant or a process in order to overcome them in time.

The Chernobyl and other major industrial accidents have provided a convincing answer to the question why an emphasis should be made on social dimensions of safety in complex technological systems. Only well organized and effectively run ("sustainable") societies, where developed administrative, legal and public mechanisms provide solid basis for the decisions and activities in the safety sphere, could cope with catastrophic and hardly predictable man–made and natural calamities in a most effective and sparing way.

The safety problem could be successfully (taking into account its relative character) solved only if all the safety aspects, *societal* including, are considered in their entirety, as a *system* of realistic measures and actions viewed in perspective and serving a common purpose – to prevent nontrivial industrial accidents or to essentially limit their destructive socio–economic and environmental consequences.

So, the points submitted here seem to give sufficient ground to assert that at the present stage of industrial development it is not so much the techno–engineering aspects that assure safe operation of complex industrial systems, it is their societal components which in the long run might decide the success of the industrial safety efforts.

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Quality Function Deployment in Emergency Planning and Management

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ABSTRACT

Quality Function Deployment (QFD) is an engineering tool for organizing and ranking information into matrix form in order to understand the attributes or actions that are needed to achieve a common goal, and to align cross-functional teams strategically to quickly and efficiently meet that common goal. Although this tool has been used primarily in the manufacturing world for product or process planning, it can easily and effectively be applied at various levels within the emergency planning/ response environment as an aid to prioritize critical resources. Applications will be discussed at the personal or user level, local emergency response level, state and federal levels. By utilizing QFD, these entities will be better able to address emergency situations. QFD can also be a cornerstone to continuously improve readiness to handle the crucial time just prior to, and just after, the emergency occurs.

INTRODUCTION

Quality Function Deployment (QFD) is a dynamic planning and analysis tool that can be used in numerous ways to assist in organizational planning and decision making. QFD organizes and ranks information into matrix form in order to understand the attributes or actions that are needed to achieve a common goal, and as such provides a good planning tool for emergency management planners and engineers. Brainstorming, a proven method of effectively gathering information from a large number of people can be more effective when done in conjunction with QFD.

QFD originated in Japan as an outgrowth of work done by Dr. W. Edwards Deming, an American statistician, at the end of World War II. The Japanese, with their industrial base destroyed, needed to rebuild in an expedient and efficient manner. QFD was one of the tools that was developed in order to take into account the expertise of various management roles throughout a company, and use that expertise to prioritize improvement efforts. In the mid-1980's, as a number of American industries found themselves now overcome by Japanese competitors, they went to Japan and discovered that QFD was one of the essential tools that helped in Japan's amazing economic recovery. Since QFD came to be used in the US, companies such as Ford Motor Co., IBM, Hewlett-Packard, Allied-Signal Aerospace, have used QFD to strategically plan for improvement projects, product mix decisions, service issues, etc.

This paper will illustrate how QFD can also be used to help in emergency planning and engineering. Examples at the end of the paper show applications for use at the individual user level, at the local response level and at state and federal levels. The examples will be illustrating hurricane preparedness in the state of Florida, but are general enough to show how QFD can be used in other emergency planning in other locations and with other scenarios.

HOW QFD IS DONE

QFD is also know by the term "House of Quality", due to the distinctive shape of the matrix, see Figure 1. The matrix is created sequentially, with the discussion of critical issues at each stage done in a structured, efficient manner. Often more than one matrix is created for a topic. The first matrix is a high level overview, succeeding matrices are a flow-down of more detail, possibly focusing only on one sub-topic each.

Creating the Grid

The right side of the matrix consists of a list of "what's". Although in the original uses of QFD this is a list of customers' expectations, for emergency planning purposes, this can be a list of what is needed to be done in pre-disaster or post-disaster planning. A variation on this part of the matrix is to create a primary, secondary and even tertiary lists that get further and further into specific detail.

Across the top of the matrix is the list of "how's". This list is created after the "what's" and should be done separately, but of course can be cross-referenced against the first list. In the case of an emergency management application, the methods used by the agency to carry out the pre-disaster / post-disaster activities may be a part of this "how's" list.

The next stage of the matrix is the point where the relationships between the what's and the how's are determined. This grid is filled in by looking at each "what" and determining the strength of it's relationship to the corresponding "how" using ranked values. A very strong relationship is given a value of 6. A strong relationship is given a value of 3, and a weak relationship, a value of 1. In the case of no relationship between a what and a how, the square is left blank, and has a corresponding value of 0.

A column is placed just next to the list of "what's" (the tertiary or final list) that ranks the importance of carrying out each item. These ratings are given a rank of:

5 = mandatory
4 = necessary
3 = desirable
2 = minor
1 = minimal

The correlation matrix, located above the "how's", is known as the roof of the house. This part of the QFD chart uses symbols to define the relationship matrix, and determines the strength of the technical interrelationship between each of the "how's". A strong positive relationship is designated by a solid circle, a positive relationship is designated by an open circle, a negative relationship is an "x", and a strong negative relationship is a "double x". No numerical ranking is used in this section but is instead used to facilitate discussion, and will possibly influence the final outcome.

Prioritizing the Information

At the bottom of each "how" column a tally is made. This tally is the sum of each "what" importance value multiplied by the values in the relationship matrix.

The final part of the basic QFD chart consists of an evaluation of "how well" each of the "what's" is currently being executed. For disaster planning purposes this can be a ranking of how well that particular activity was carried out during the last few same-type disasters. See the following example for clarification.

USING QFD FOR EMERGENCY PLANNING

Each agency who is involved in the management of emergencies may have its own QFD application and houses of quality. The following list provides first level QFD matrices for local, state and federal emergency management efforts. In each case we list the potential "what's" for the agency followed by the "how's". Naturally, if desired, in the next level of QFD matrices we may list the "how's" of the first level as "what's" of the second level, in a cascading manner. We must then develop the necessary "how's" corresponding to these new "what's" at level two. This hierarchical decomposition of "how's" and "what's" may be continued to the level of detail needed by the specific agency.

QFD for Local Response

The QFD analysis can serve good purpose in helping local agencies provide quick and adequate response to disasters. A partial example consisting of a list of "what's" and "how's" for the local emergency management team at level 1 follows.

What's

- Provide timely and accurate storm information
- Provide adequate safety
- Provide rapid mitigation efforts
- provide adequate shelters
- Provide adequate guidance
- Provide basic needs
- Provide outside communication

How's

- Accurate tracking of storm
- Accurate estimate of landfall/ consequences
- Accurate estimate of resource needs prior to landfall
- Accurate estimate of resource needs during the hurricane landfall

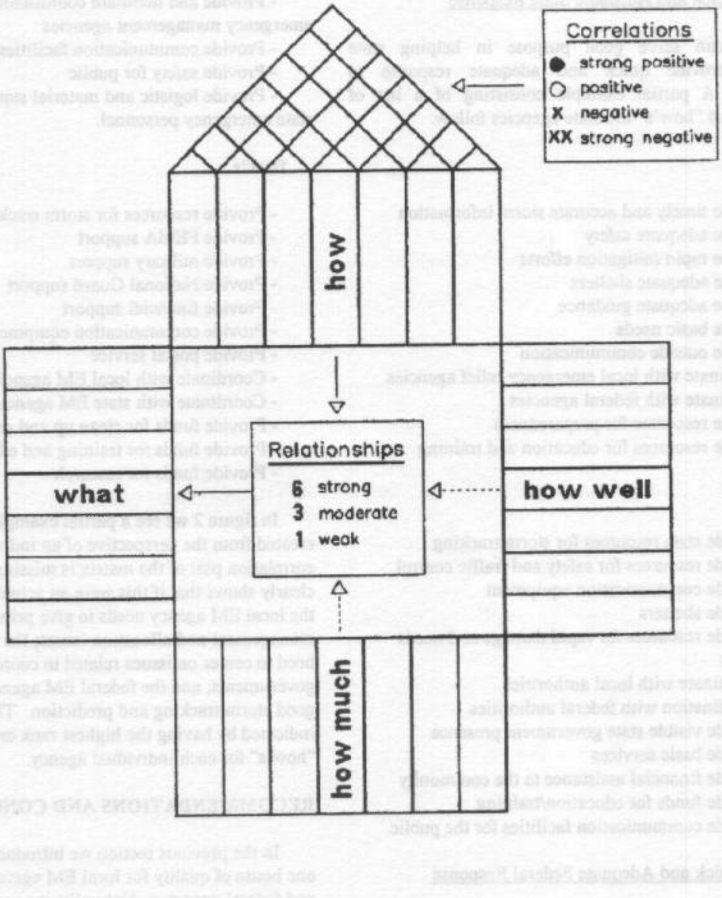

Figure 1. A Sample House of Quality

- Accurate estimate of resources needed after the hurricane
- Population/crowd control before, during and after the hurricane
- Resource management and allocation
- Traffic control for better evacuation
- Shelter management for optimal shelter utilization
- Provision of basic services for sheltered people
- provision of postal and telecommunication facilities for the residents

QFD for Quick and Adequate State Response

QFD can serve good purpose in helping state agencies provide quick and adequate response to disasters. A partial example consisting of a list of "what's" and "how's" the state agencies follow.

What's

- Provide timely and accurate storm information
- Provide adequate safety
- Provide rapid mitigation efforts
- provide adequate shelters
- Provide adequate guidance
- Provide basic needs
- Provide outside communication
- Coordinate with local emergency relief agencies
- Coordinate with federal agencies
- Provide resources for preparedness
- Provide resources for education and training

How's

- Provide state resources for storm tracking
- Provide resources for safety and traffic control
- Provide communication equipment
- Provide shelters
- Provide resources for rapid damage and needs assessments
- Coordinate with local authorities
- Coordination with federal authorities
- Provide visible state government presence
- Provide basic services
- Provide financial assistance to the community
- Provide funds for education/training
- Provide communication facilities for the public`

QFD for Quick and Adequate Federal Response

QFD can serve good purpose in helping federal agencies provide quick and adequate response to disasters. A partial example consisting of a list of "what's" for federal government follows.

What's

- Provide quick federal presence
-Provide resources for mitigation efforts
- Provide resources for preparedness
- Provide resources for training and education
- Provide and maintain coordination with local emergency management agencies
- Provide and maintain coordination with state emergency management agencies
- Provide communication facilities for the public
- Provide safety for public
- Provide logistic and material support to local and state emergency personnel.

How's

- Provide resources for storm tracking
- Provide FEMA support
- Provide military support
- Provide National Guard support
- Provide financial support
- Provide communication equipment
- Provide postal service
- Coordinate with local EM agencies
- Coordinate with state EM agencies
- Provide funds for clean up and rebuilding
- Provide funds for training and education
- Provide funds for research

In figure 2 we see a partial example of a QFD chart created from the perspective of an individual. The "roof" correlation part of the matrix is missing, but the chart clearly shows that if this were an actual working chart, the local EM agency needs to give priority to its resource management and allocation issues; the state EM efforts need to center on issues related to coordination with local governments; and the federal EM agencies need to assure good storm tracking and prediction. These priorities are indicated by having the highest rank on the list of "how's" for each individual agency.

RECOMMENDATIONS AND CONCLUSIONS

In the previous section we introduced a sample level one house of quality for local EM agencies, state agencies and federal agencies. Naturally, we can continue this hierarchical decomposition by making the "how's" at

	Priority	Quick Lcl. Resp.	Coord. w/ St. & Fed. Gov.	Accur. & Timely Storm Inf.	Resource Estimation	Crowd Control	Resource Mgt. & Alloc'n	Evac. Traffic Control	Shelter Mgt.	Provide Communication	Provide Basic Services	Quick St. Resp.	Coord. with Federal Govt.	Coord. with Local Gov't	Presence of Law Enf.	Presence of St. Auth.	Disaster Declaration	Rescs. for Lcl. EM Team	Financial Aid to People	Provide Training	Quick Fed. Resp.	Pres. of Fed. Auth.	Disaster Declaration	Provide Materiel to State	Provide Relief Funds	Provide Research Funds	Storm Tracking and Pred.	Provide Law Enforcement	
Effective Relief Support	4		6		6		6	3	3	6	6		6	6	6	6	6	6	6	6		6	3	6	6		6	6	117
Law Enforcem't/ Security	4		6		6	6	6	6	6	6	6		6	6	6			6		6		6		1			6	6	97
Urban Search & Rescue	5		6		6	1	6	6		6	6		6	6	3			6		6		6		6			3	6	85
Mass Care & Transport'n	5		6		6	3	6	6	6	6	6		6	6	6			6	6	6		6		6		6	6	6	111
Quick Return to Normalcy	3		6		1	6	6	6	6	6	6		6	6	6	6	6	6		6		6	6	6	6		6	6	121
Fire Fighting	4		1		6	1	6	6		6	6		6	6	6			6		6		3		6		6	6	6	89
Food	5		3		6	6	6	6	6	6	6		6	6	6			6		1		3		6			6	6	91
Water	5		6		6	6	6	6	6	6	6		6	6	6			6		1		3		6			6	6	94
Materiel for Rebuilding	4		3		6	6	6	6		3	6		6	6	6	1	3	6	6	1		3		6	6	6	6	6	104
Financial Support	3		6		3	6	6			6	6		6	6		6	6					6	6		6		6		81
Public Works & Equipm't	4		6		6	1	6	1		1	6		3	6	1	6	6	6		6		3		6		6	6		82
Effective Shelter Mgt	3		1	1	3	6	6	3	6	6	6		3	6	6	3		6		6		3		3			6	6	86
Communicat'n & Command	4		6	1	1	1	3	3	6	6	6		6	6	3	3	1	6		6		3	3	6		6	1	6	89
Effective State Help	4		6	6	6	1	6	6	3	6	6		3	6	6	6	6	6	6	6		3	6	3		6	6	6	121
Effective Federal Help	4		6	6	6	1	6		1	6	6		6	3	6	6	6	3	6			6	6	6	6	6	6	6	116
EM Personnel Assignm't	4			6	6	6	6	6	6	6	6			6	1	1	1	6		6		3		1			6	6	85
Effective Rumor Control	3		3	6	1	6	1	3	6	6	6		3	6	6	6	1	1		6		3	3	3	3		6	6	91
Effective Resource Alloc'n	3		3	6	6	1	3	3	6	1	6		6	6	6	1	1	6		6		3	1	3	6	1	6	6	93
Contin. Update of Situat'n	5		6	6		6	3	3	6	6	3		6	6			1	1		6		1	1				6	3	70
Effective Damage Estimate	3		6	6	1		1			6			6	6		6	6	6		6		3	6			3	6	3	77
Good Evacuation Time Est.	4		6	3		3	6	6	6	3			6	6	1	1		6		6		3		3		3	6		74
Good Evacuation Popul Est.	4		6	6	6	3	6	1	6	3			6	6	1	1		6		6				3		3	6		75
Good Damage Estimation	4		6	6	6		3						6	6	1	3		6		6				3		3	6		61
Good Storm Tracking	5		6	6	1	3	6	3	3		1		6	6		3		6		6		3		6		6	6		77
Resource Allocation	4		6	6	6	1	6	3	3		3			3	1	3		6		6				6		3	6	1	69
Effective Traffic Control	3		3	6	1	6	6	6	6		3			3	1	3		6		6				1		3	6	3	69
Effective Shelter Assignm't	3		1	6	6	6	6	6	6					3		3		6		6				1		3	6	3	68
Broadcast Information	5		1	6	1		1	6	6	6				3		3		3		1		1					6		44
Published Preparedness Inf.	3		1					6	6	3			1	3	1	3	1												25
Published Shelter Inf.	3		1					6	6	3			1	3	1	3													24
			519	343	464	356	563	485	469	499	467		516	627	366	298	184	581	126	529		343	143	425	135	282	631	430	

Figure 2. A House of Quality from Individual's Perspective

level one the "what's" at level two, the "how's" at level two the "what's" at level three, etc.

With the cumulative importance rating of each "how" the appropriate agency may prioritize the action plans and focus on the ones that needs improvements.

Furthermore, comparing how the previous hurricane efforts fared on each "what" item, we can assess the "how's" we need to focus on to improve the ratings on particular "what's".

QFD provides us a systematic and integrative method to evaluate our past performance and map out our future direction in improving the quality of our emergency response in dealing with hurricane emergencies.

QFD can become an invaluable tool in planning for both pre-disaster, during and post-disaster activities. Much of what is learned in handling one disaster can dissipate quickly after debriefing meetings occur. QFD can be used as a method to assure that that does not occur.

Disaster planning agencies using QFD will find their weaknesses and will be able to use QFD as justification for bolstering weaknesses.

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Computerized Tactical Training for Emergency

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MULTI-USER SYSTEM FOR TRAINING AND EVALUATION OF ENVIRONMENTAL EMERGENCY MANAGEMENT RESPONSE - MUSTER[1]

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ABSTRACT

The efficiency with which complex, large-scale organisations respond to emergencies and critical situations depends crucially on the co-ordination of actions and communication among decision makers. However, decision makers have typically few opportunities to train distributed crisis management under artificial, yet realistic conditions; and at the same time, real emergencies occur fortunately so relatively infrequently that few decision makers have a chance of establishing a useful real-life experience of crisis management. There is therefore a need for having available realistic and flexible multi-user training environments in which co-ordinated response to crises or emergencies may be trained.

At the same time, a flexible training environment supporting tactical training of co-ordinated emergency response can be used as a platform on the basis of which not only emergency response capability can be evaluated but also different procedures and practices and even control systems may be assessed before they are put into real use.

In order to identify requirements to, develop specifications of and finally produce a prototype of a flexible training and evaluation environment, a two-year project, MUSTER: 'Multi-User System for Training and Evaluation of Environmental Emergency Response' was started in 1993 and is now approaching its completion by mid-95. The project, which is supported by the ENVIRONMENT programme of the Commission of the European Union and which comprises nine partners in four countries, has selected railways and port areas as its two target applications.

INTRODUCTION

MUSTER - Multi-User System for Training and Evaluation of environmental Response, is a training system especially dedicated to improve the co-ordination of efforts of decision makers in emergency management. The project was initiated in 1993 and planned for two years; it includes nine participants from four different European countries, and it is partially funded by CEC.

Even though experience is the most efficient way to train how to handle difficult situations, the real world is not necessarily the best teacher; partly due to the low frequency with which specific emergency situations arise, and partly due to the risk in provoking dangerous situations just in order to build up the experience necessary for maintaining a high and effective preparedness for possible future hazardous events.

So, due to the fortunate low frequency of major emergency situations, training of emergency management organisations is of vital importance in order to minimise the consequences of catastrophic events. The entire emergency management organisation coping with large emergency situations is normally built up by various units like fire brigades, police forces, civil defence, hospitals, etc., and the skills to be trained exist mainly on three different levels: the skill of the individuals in each of these units, the efficiency of each unit per sey, and finally, the co-ordinated performance of the units in order to obtain the optimal emergency management and efficiency.

The individual skill as well as the separate efficiency of each organisational unit are effectively trained inside each unit by frequent exercises and drills, and their

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[1] This work is partially supported by CEC Environment Programme, proj. PL 910675

optimisation is not the goal of the training supported by MUSTER.

The Objectives Of MUSTER

The goal of MUSTER is to develop advanced and efficient means of supporting the co-operative training among the various units forming the complete emergency management organisation. One way of carrying out co-operative training is full scale exercises, i.e. exercises in which all aspects of emergency response are carried out physically. Only the physical process of the emergency, the fire, the explosions, etc. is not present.

Full scale exercises are the most realistic training set-up in order to train all aspects of a co-ordinated emergency response: technical and physical skills including the technical and physical co-ordination, management and communication including the managerial co-ordination, and the state of initial preparedness. Figure 1 indicates a full scale training exercise with the emergency management resources represented partly at the site of the emergency and partly in remote command centres. The resources in a full scale exercise are normally the same as those involved in a real emergency situation, and this may easily add up to a huge amount of people. This is, therefore, typically an extremely expensive form of training, and even more, a form which is difficult to control in detail. Thus, it is often infeasible to pause or revert in case the evolution does not follow the line planned in advance in order to convey the most efficient training in relation to the objectives of the training session.

In order to overcome the drawbacks of full scale training, training systems like MUSTER are used. The support offered by MUSTER embraces the phases of planning, execution, and evaluation. Similarly, the objectives of MUSTER are threefold:

- to support trainers or "drill supervisors" in the planning phase - by offering an authoring environment - in developing training scenarios based on specific training needs, the possible vulnerable objects, and the available resources, human as well as technical;
- to support the supervisor and his aides during the execution of a training scenario, by offering a simulation of the emergency environments giving the

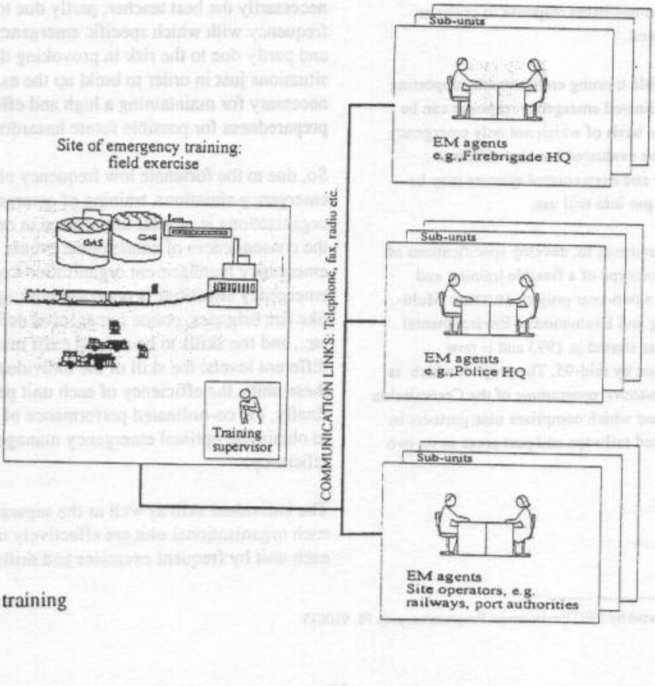

Figure 1 Full scale training

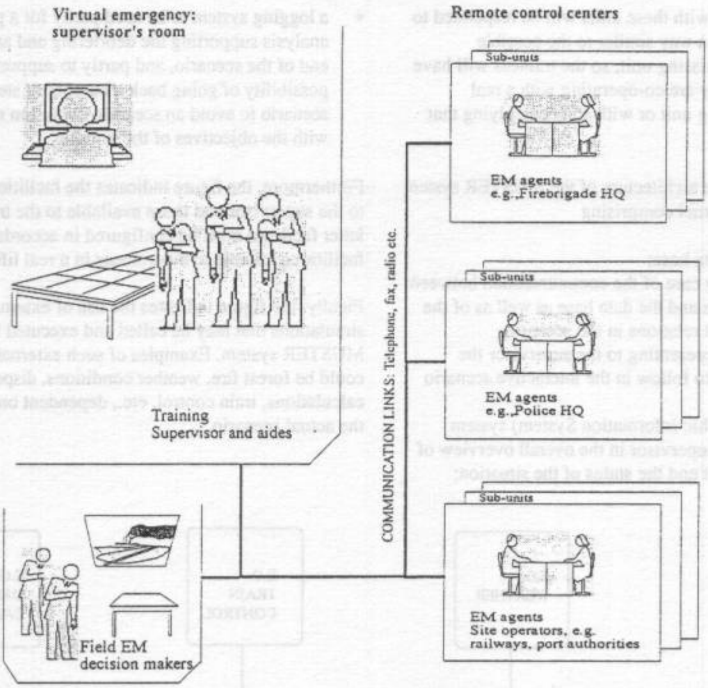

Figure 2 Simulated environments

supervisor the best possible overview of the situation, the events automatically or manually carried into effect, and the actions of the trainees; furthermore, to support the presentation of the actual situation to the trainees in a plausible way as compared with the visual impression they would have in a real life situation;

- to support the supervisor in the debriefing or evaluation phase by allowing him to review and present in an easy way specific situations selected during the scenario execution.

Figure 2 shows the simulated emergency situation with the decision makers situated partly in a training location giving presentations of the scenario as mentioned above, and partly located in the remote command centres in the same way as for a real emergency situation.

One objective of the simulation of the emergency is to present to the training supervisor the virtual world in the best possible way in order to support his overall view of the situation, and to update him continuously about all events and actions taken either automatically by the system in accordance with the scenario planning, by the supervisor himself in accordance with the scenario planning or initialised due to the wish of changing the current stress of the scenario, or by the trainees in response to the scenario. Another objective of the simulation is to present to the trainee part of the virtual world in accordance with the information they would have had in a similar real life situation and based on which they must build their own mental model of the complete scenario.

Besides the ability to control the training scenario in high details by using the training environments, this will moreover allow training of a selected part of the emergency managing units by letting the role of the remaining parts be taken by the supervisor or his aids.

All communication with these units will be responded to by the supervisor in a way similar to the possible response from the missing unit; so the trainees will have no indications if they are co-operating with a real emergency managing unit or with someone plying that role.

Figure 3 displays the architecture of the MUSTER system with a MUSTER kernel comprising

- a centralised data base;
- a handler taking care of the communication between various modules and the data base as well as of the timing of causal relations in the scenario;
- a scenario tree presenting to the supervisor the possible routes to follow in the interactive scenario execution;
- a GIS (Geographic Information System) system supporting the supervisor in the overall overview of the environment and the status of the situation;
- a logging system to be used partly for a post mortem analysis supporting the debriefing and analysis at the end of the scenario, and partly to support the possibility of going back a number of steps in the scenario to avoid an scenario evolution not in line with the objectives of the training.

Furthermore, the figure indicates the facilities available to the supervisor and those available to the trainees. The latter facilities must be configured in accordance with the facilities available to the trainees in a real life situation.

Finally, the figure indicates the use of external simulations that may be called and executed by the MUSTER system. Examples of such external simulation could be forest fire, weather conditions, dispersion calculations, train control, etc., dependent on the needs of the actual scenario.

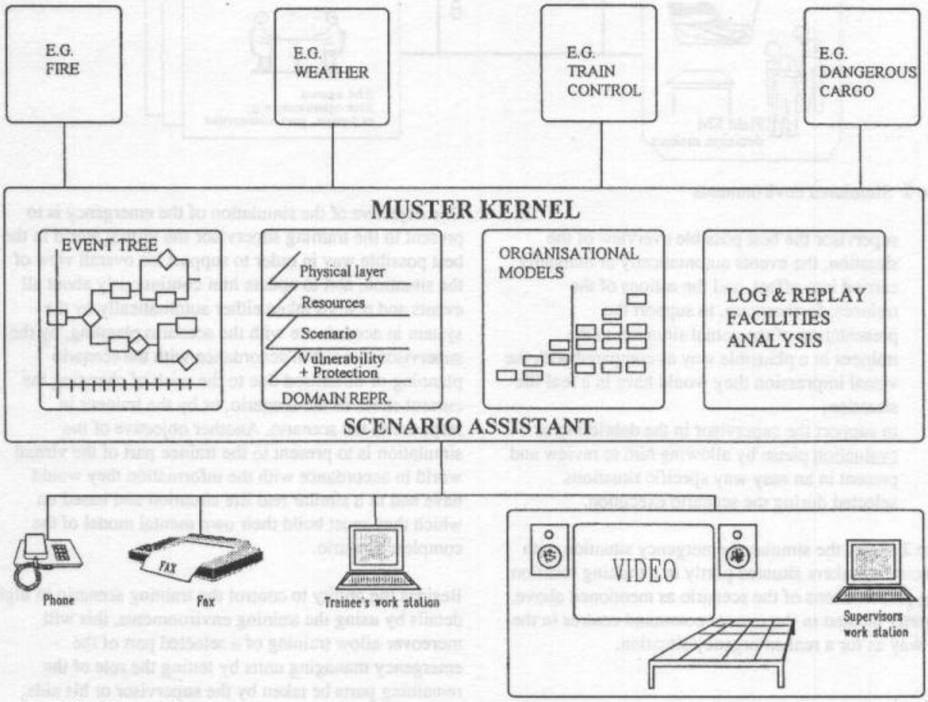

Figure 3 MUSTER architecture

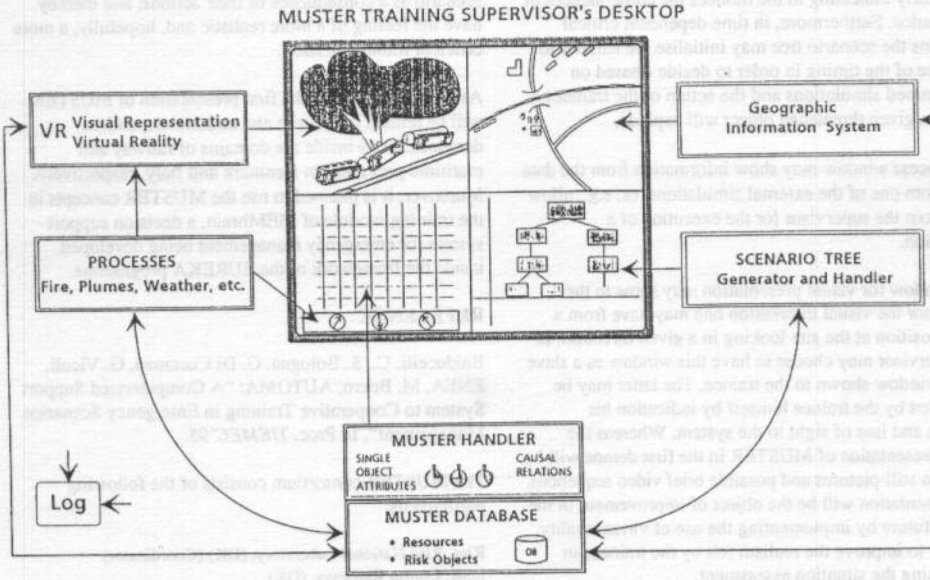

Figure 4 Supervisor's desktop

Based on the MUSTER kernel and the choice of external simulations, a large variety of scenarios may be fulfilled by the use of MUSTER. However, the first phase of demonstrations of MUSTER scenarios will be limited to two domains:

- one is the railway domain based on a fictive accident at the Danish railway comprising derailed tank wagons of which one is leaking toxic materials to be dispersed in the environments, and another one is jeopardised to explosion due to a nearby fire;
- the other is the port domain based on a real accident in 1982 in the port of Genoa comprising an explosion in an oil tanker with the implications of emptying the port area for other tankers jeopardised to the same destination. (see Balducelli et al.)

Figure 4 indicates the supervisor's desktop that will show at least four different views of the situation presented either on one screen as shown on the figure or on a couple of screens.

The GIS system will be performed using MapInfo, and it will probably have its own screen of presentation. It will present the overall view of the scenery, showing the environment, the scene of action including the threatened object and the resources available for the rescuing process. In case of fire the GIS system will show isocurves of temperatures to indicate the area in which rescuing people may or may not act. Likewise, in case of release of toxic materials, the GIS system will show isocurves of the concentration of the toxic cloud in order to indicate the risk of victims and consequently the order in which they should be rescued; and furthermore, the isocurves will indicate the need of protective equipment for the rescuing personnel. Moreover, in relation to the window of visual presentation the GIS window will indicate the line of sight of the decision maker at the site with subsequently consequences for the information to be shown for the trainee.

The scenario tree will support the supervisor during the execution of the planned scenario as well from the point of view of reminding him of his own choices at a given time of the scenario as from the point of view of indicating reasonable choices of the trainees in specific critical situations. In order to have realistic scenarios, the MUSTER system is an interactive system; so, these choices will influence the evolution of the scenario in a way clearly indicating to the trainees the consequences of their choice. Furthermore, in time dependent critical situations the scenario tree may initialise the handler to take care of the timing in order to decide - based on programmed simulations and the action of the trainees - if, e.g., a given threatened object will explode.

The process window may show information from the data base, from one of the external simulations, or, e.g., allow input from the supervisor for the execution of a simulation.

The window for visual presentation may show to the supervisor the visual impression one may have from a given position at the site looking in a given direction; or the supervisor may choose to have this window as a slave of the window shown to the trainee. The latter may be controlled by the trainee himself by indication his position and line of sight to the system. Whereas the visual presentation of MUSTER in the first demos will be based on still-pictures and possible brief video sequences, this presentation will be the object of improvement in the nearest future by implementing the use of virtual reality in order to improve the realism felt by the trainees in performing the situation assessment.

MUSTER Achievements

Whereas most computerised training systems today have a sequential succession of events regardless of the counter actions of the trainees, the most important result of MUSTER is the development of an interactive training system in which the trainees will see the influence of the scenario as a consequence of their actions; and thereby have the feeling of a more realistic and, hopefully, a more efficient training session.

As mentioned above, the first presentation of MUSTER will be related to two site and national dependent demonstrations inside the domains of railway and maritime port areas in Denmark and Italy, respectively. Moreover, it is planned to use the MUSTER concepts in the training module of MEMbrain, a decision support system for emergency management being developed inside the framework of the EUREKA programme.

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DTI, Danish Technological Institute, (DK)
CRI, Computer Resources International A/S, (DK)
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HANDLING EMERGENCY MANAGEMENT TRAINING SCENARIOS: THE MUSTER SCENARIO MANAGER

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ABSTRACT

The SCENARIO MANAGER is a module within the MUSTER system: a prototype computer system supporting the multi-user training of emergency managers and their staff in co-ordinating activities to cope with emergencies. The overall architecture of and requirements to the MUSTER system is described in the accompanying paper (V. Andersen & HB Andersen, 1995); see also accompanying papers by Balducelli et al. 1995, Hansen et al., 1995) The SCENARIO MANAGER has been designed to meet the requirements of training supervisors, that is, the persons (including aides) who plan, execute and analyse training sessions for emergency management trainees.

INTRODUCTION

The purpose of the SCENARIO MANAGER is to provide a flexible tool which supports the organisation and administration of training scenarios for emergency management training. In particular, the SCENARIO MANAGER is designed to support training supervisors in the three key stages of their tasks, namely the planning, execution and post-session analysis of training scenarios. The SCENARIO MANAGER is one of the modules of the MUSTER system but it may serve as a stand-alone system for scenario planning, while its role as supporting execution can be achieved only when it is linked up with other modules simulating target processes (toxic releases, fires etc.) and resource management. See the overview paper by Andersen & Andersen, 1995, which provides an introduction to the overall MUSTER system.

The objectives behind the design of the SCENARIO MANAGER are to provide support to training supervisors in accomplishing a range of tasks in handling complex training scenarios. There are two problems in particular which we have sought to address by designing the SCENARIO MANAGER. One problem is to do with the rigidity of even moderately complex training scenarios - this has to do with the degree to which the actual trajectory of events and actions during the unfolding of the scenario is determined by the decisions of the trainees. The second problem concerns a problem for supervisors in maintaining an overview of options and choice points during his planning of a training scenario and, even more critically, during its execution.

When the MUSTER project was planned, one main goal set out initially was to provide a flexible multi-user training environment which would allow trainees an opportunity to train their skills against realistic simulations of the types of physical (and social) events with which they need to cope during real incidents or disasters. Thus, the MUSTER system seeks to replace, for the relatively narrow purpose of training decision makers, large-scale field exercises during which trainees may command the deployment of units who cope, not with computer simulations, but with more or less realistic fires, the rescuing of 'wounded people' and other events that are included in physically simulated emergencies. There are, of course, several well-tested and in many respect excellent alternatives to field exercises when focusing on training co-ordination and decision making. The most frequently used method is to use some form of table-top tactical trainer environment which provides a 'mini-world' played out on a table-top and where the virtual emergency scenario is played out by physically simulating deployment of resources and movement of 'risk objects' (wounded people; people at risk, hazardous materials etc.). See in particular Haurum 1995.

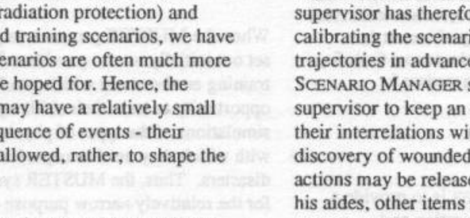
In contrast, the approach chosen in the design of the MUSTER system has been to allow trainees to cope with computer simulations of events and situations - and although we do not wish to criticise the often excellent training practices and effects observed in connection with table-top tactical training, we believe that computer simulation of events and processes can provide added realism, or at least different aspects of realism, to the training. Given, therefore, the goal of creating a flexible training system that allows trainees to cope with computer simulated events and situations, the problem of managing and keeping an overview of a scenario that involves interactive simulations becomes acute. Consider, in contrast, a large-scale field exercise. Since the logistics of such a scenario demands it that the sequence of nearly all main events are planned well in advance, the scenario will often appear, and will often be, rather more deterministic than would be the case in the real world. That is to say, since many or most of the major events have to be planned in advance, the decisions of the trainees, including their co-ordination and communication, will tend to have less of a causal influence on events than would be the case in the real world. Indeed, having interviewed a number of training experts and supervisors at various training schools (military, civil protection, firebrigades, railway emergency management, radiation protection) and having surveyed associated training scenarios, we have concluded that training scenarios are often much more deterministic than could be hoped for. Hence, the decisions by key trainees may have a relatively small influence on the actual sequence of events - their decisions and actions are allowed, rather, to shape the form and "size" of events.

In a table-top exercise, there is no need to establish a logistics planning at the same degree of detail and depth; the training supervisor and his aides may flexibly respond, by running the physical simulation of events by way of movements and indications on the table-top, and by providing plausible and non-deterministic responses to the decisions, commands and communications made by trainees. The only major drawback, it appears, is that trainees may lose the illusion that they are coping with an 'objective' situation rather than coping with the intentions and plans of the training supervisor.

The approach of the MUSTER system is therefore to allow a high degree of free choice and causal influence by trainees on the virtual events. This, however, does not mean that a training session necessarily requires less planning - it may do so, but that depends on the training goals and the type of scenario chosen. In general, to set up a training scenario requires that the training supervisor has drawn up in advance the main choice points during the scenario. Since the MUSTER system involves computer simulations of physical processes it is expected that a training supervisor who uses the system will, during the planning phase, run several mini-simulations in order to calculate critical parameters so as to make the scenario challenging but not impossible to cope with (i.e., he may calculate, say, the distance he wants to have between his initial fire and a neighbouring fuel tank allowing trainees sufficient time to cool the tank, if they act quickly). Having allowed trainees the liberty to interact with simulations, rather than improvised decisions by the supervisor and his aides, the supervisor has therefore a greater need for planning and calibrating the scenario and its different possible trajectories in advance. Hence, the design of the SCENARIO MANAGER seeks to satisfy the need of the supervisor to keep an overview of the 'choice points' and their interrelations with other outcomes (e.g., explosions, discovery of wounded people). Some of these events and actions may be released or initiated by the supervisor and his aides, other items may be released by the simulations or even predetermined parameter changes (change of wind direction etc.)

Underlying logic

The underlying temporal representational system on which the design of the SCENARIO MANAGER has been based is branching time logic. A branching time logic will contain a designated, perpetually moving NOW,



and every event that lies 'before' the designated 'now' is fixed and unchangeable and is located timewise on a single unbroken line stretching backwards. When we write it down on paper we usually go from left to right, so events in the past lie to the left of the designated 'now'. whereas events 'after' the designated NOW branch out into different futures.

In logic, the principle according to which a new branch is introduced (a 'choice point') is as liberal as possible: if the wing of the butterfly goes up, the future goes in one direction; and if it goes down, the future goes in another direction. For practical purposes we do not want to be nearly so liberal in acknowledging a new scenario trajectory: only "important" differences make a difference sufficient to warrant an explicit bifurcation of the training scenario. In this connection, a training supervisor (TS) will often introduce what we may call *alignments*. An *alignment* is a response by the TS or the training environments which takes into account that the trainees may do A or B and which brings the scenario back to the course laid down by the TS. So while A normally would lead to A*, say, and B to B*, a TS may decide that B* is much more valuable for the training session and he will therefore in the planning phase (or at the spur of the moment) introduce a perturbation so that even though trainees chose A and not B, the course of events nevertheless develop into course B*.

When we create a tree in which nodes represent important 'choice points' or important alternatives determined by events or non-trainee actions we shall speak of a *Scenario Tree*, see example below..

Implementation

In the following we describe only very briefly the implementation of the Scenario Manager, including a characterisation of its associated data structure and the principles behind the design of the *Scenario Tree* window. For a more complete description, please confer Larsen et al. (1995).

Terminology

In the Scenario tree we have *Events, Actions* and *Notes*. An *Event* is shown as a box in the main scenario tree and consists of a number of actions. An *Action* is the actual decision, action or event that make up part of the Event to which the action is attached. Actions are shown in two windows at the bottom of the Scenario Tree workspace, and describe the events in further detail. Finally, *Notes* are small reminders and comments. These can be owned by any external unit, and can be timed to any time in the scenario. In other words, in the railway scenario used as the demonstration scenario for the Danish version of the MUSTER prototype, there may be a set of notes for supervisor as well as a set of notes for the remote control centre. Notes may be connected to events. In Balducelli et al. 1995, the concept of Events and Actions is also referred to as 'nodes', conveying well the logical notion of choice points in a tree-like structure.

Selected technical features

The Scenario Tree Handler is able to draw a scenario tree on the basis of the underlying data supplied by the Training Supervisor when setting up the scenario script (the details of how the handler automatically generates a tree is described in Larsen et al. 1995). The Scenario Tree Handler must not only be able to draw a scenario tree but must also be able to animate the movement and changes to the tree during the execution of the scenario. Whenever an event in the tree reaches current time ('now') it will either be invoked automatically, or it will wait for someone (the training supervisor or one of his assistants), to acknowledge the event. What happens depends on how the event is timed.

Automatic invocation of actions: The Scenario Tree Handler will support automatic invocation of actions. Thus when an action is acknowledged, a set of objects and states will be set in the Muster Database, thus actually performing the actions in the system.

Automatic detection of externally invoked actions: The Scenario Tree handler will not automatically detect whether a specific action has been invoked. It will, however be possible for other programs to change the status of single actions in an event, thereby making the tree, proceed in the scenario.

Change of time-scale: The Scenario Tree handler may support changing the timescale in the Tree-window. This way it will be possible to make a "temporal zoom". By using temporal zoom the user can get a better overview of the scenario.

Change of Information Detail: The Scenario Tree handler may support different levels of detail in the objects displayed. In this way it will be possible to show the objects in different ways, making it possible to select a suitable balance between information detail and information overview.

The Overall Application Workspace

In the present paper there is no space for describing the technical details in even superficial form of the application - please confer the report by Larsen et al. (1995) for a complete description.

The Scenario Tree is presented in a stand-alone Visual Basic application. This application contains 4 windows, as outlined in figure 1. .

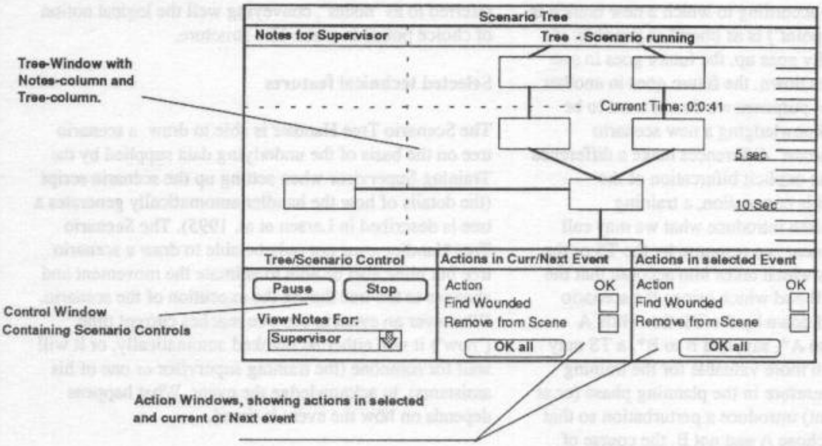


Figure 1: The Scenario Tree Workspace

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A COMPUTERIZED SUPPORT SYSTEM TO COOPERATIVE TRAINING IN EMERGENCY SCENARIOS MANAGEMENT AND ITS APPLICATION TO AN OIL PORT DOMAIN

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ABSTRACT

The paper describes part of the results achieved in the framework of the MUSTER[1] project (Multi-Users System for Training and Evaluating Environmental Emergency Response). The aim of this project is to define the detailed specifications of a computer based system supporting collaborative training for emergency management. A system prototype has been implemented to support the refinement and improvement of the system specifications.

INTRODUCTION

Collective training, a novel type of computer based training, is aimed to improve the coordination level inside multi-agents organizations and to evaluate the emergency procedures and the effectiveness of the utilized tools and devices (*Balducelli, Gadomski 93*). In fact, in the framework of situations having an high environmental risk, like ports and/or areas with an associated high energy density, the emergencies are managed by different types of authorities. Every actor, during the emergency , has his own responsabilities and defined procedures to follow but, very often, the execution is not adequate to the mutual coordination of the respective tasks.

Now it is recognized that the efficiency of an emergency management organization mainly depends on the coordination of actions among the involved decision makers.

To improve the intervention efficiency the emergency organizations execute periodically exercises on the territory: these exercises are realistic but they have a very high costs and, in addition, it is not always possible to simulate all the hypothetical accidents. An additional training method is the computer based training that exploits the simulation capability of the system. This method has a low level of realism but the costs are lower and allows to explore a wide range of situations.

For these purposes, besides to provide a real scenario specifications, the italian participants to the MUSTER project (*Andersen H.B., Andersen V. 1993*) have developed a computerized support system prototype based on an high risk area (an Oil Port in Italy) and on a true emergency event occurred some years ago (a tanker explosion in the same area). The prototype architecture consists of a network of personal workstations. In particular, the demonstrated training session is composed by a Supervisor and two trainees with their workstations.

The supervisor has the task to plan the training session (this can be done long time before the training session), to illustrate the session, to control the exercises execution and to evaluate the results. The trainees, through their workstations, perform actions on the scenario. In the demonstrated session one trainee represents the on-field coordinator (the coordinator agent operating near the accident, OFC), the other trainee represents the on-site coordinator (who in this case is the Oil Port director, OSC).

In the paper we will present the general requirements for the prototype, the architecture of the system and preliminary feedbacks from the end-users.

THE COOPERATIVE WORKING FRAMEWORK

Since MUSTER is a multi-user training system, one of the main issues addressed during design was the definition of an appropriate reference model for cooperative working (CW). The model adopted, from the one hand provided the conceptual background to investigate and specify the general

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[1] MUSTER is a CEC funded Project in the framework of the DGXIII ENVIRONMENT Programme.

requirements of the MUSTER system, and, on the other hand, allowed to identify some components for the implementation of the system itself. The CW model adopted in MUSTER provides a description of the organisational structure, of the individual and cooperative tasks and of the intercommunication and behaviour of the agents involved in the management of an emergency situation. Given the general objectives of MUSTER (i.e. training of coordination of emergency management managers and *not*, for instance, the operational training of emergency-fighting staffs like fire brigade etc.) only high level decision makers are considered as agents taking part in the cooperative working structure. Based on this, the MUSTER CW model consists of two main conceptual elements:

- a description of the human emergency management structure
- a specification of the network of communication, decision-making and coordination of actions among the various actors involved.

Both aspects and the main information required to develop a CW model in a particular application site was outlined in a previous work (*Balducelli, Boero, Errico 1993*).

THE SCENARIO GENERATOR

Emergency Domain Model Definitions

The Scenario Generator utilizes a Domain model that is decomposed into three main layers:

- Layout Layer; (LL)
- Resource Layer; (RL)
- Scenario Layer; (SL)

LL includes the most static knowledge of the considered territory and are represented by more or less schematic geographical maps.

RL includes the set of all the equipments, the components and the human organizations that are active on the considered territory.

SL includes the set of all the factors and events that may be considered on the territory in relation with the emergency management activity.

Layout Layer

LL represents the configuration of the territory under consideration for the emergency management activity. The main type of information included can be regarded as a set of physical constraints. For example, the port layout includes the configuration and type of piers that are constraints for ships movements. The layout is normally represented by a map, at more or less detailed level of granularity. Generally, in the proximity of accident locations, the map should be more detailed due to the increasing importance of the physical constraints in the territory, in relation with the emergency management activity. A boundary is normally present in the layout layer to divide an on-site portion of the layout from the off-site one. The on-site layout is the part of the territory under the responsability of the on-site manager (the Oil Port Authorities) normally not accessible to external people. The off-site layout is the external, public territory.

Resource Layer

With the term resource we refer to every equipment, system or component having some function or goal inside the LL. A resource may be a technical resource or a human resource. For reasons of conceptual clarity an object-oriented approach (*Coad and Yourdon 1990*) seems a quite natural choice. Using this perspective, the most general classes of objects were firstly defined. As in all taxonomies, the classes/objects may be specified at different levels of generality. Any attribute specified for a class at a general level is inherited by all subclasses/objects belonging to that class. Using this representation, the class *resource* is the most general class containing all the physical objects considered inside LL. A resource has the following general attributes: *goal*, *location* on layout, *vulnerabilty* level, *destructiveness* level, *degree of protection*. These types of attributes are applicable to all objects belonging to all subclasses. The contents of some of these, like goal and location on the layout does not depend on the scenario. The vulnerablity level and destructiveness level values may depends on the type of scenario. The degree of protection value may be strongly dependent about the resource location: for example the pipelines located on the pier nearest to an exploded tanker will need a strong degreee of protection to avoid the emergency propagating to other parts of the layout. Subclasses of the resources class are as follows:

Normal Operation Resources: these resources have the goal of supporting all the operations to be carried out inside the domain under normal circumstances. This type of resources are not directly related to emergency situations but could be involved (as *risk objects*) in the emergency or could even be a cause of an emergency situation. Resources of this type, for an oil port domain, include for instance oil-tankers, fuel loading-unloading systems, fuel containers.

Emergency Support Resources: these resources have the goal of supporting emergency operations. They may be equipments or human organizations and experts. In the oil port domain typical resources belonging to this class are the anti-fire local systems, anti-pollution systems, fire-brigades, tug-boat people, etc. Specific attributes associated to this type of resources are: availability time and amount.

Resources for Services and Utilities: these resources have the goal of supporting general services inside the layout. Electrical supply systems are one of the principal resources belonging to this class. An airport system may be another example. In general the availability of this type of resources can be of some help during the emergency situation; so a common attribute to this type of resources is availability time.

Using this type of formalization the same physical resources (human or equipment) may be instantiated with different specific attributes depending of the situation and the scenario.

Scenario Layer

This layer contains all the information related to the different kinds of factors and/or events that may emerge inside the domain and which can have some impact during an emergency situation. These factors can be classified as: *meteorological* factors, *population density* factors, *accesibility* constraints to accident location, *level of storage* of hazardous materials and other particular events. In general this layer contains all the information and events which can be hardly predicted in advance and that may influence the emergency evolution.

THE GENERAL SYSTEM ARCHITECTURE

As we can see in fig. 1, the italian MUSTER prototype configuration is composed by three workstations (one for training Supervisor and two for the trainees) connected together using Window for Workgroup system. The different tasks comunicate each other using the Network DDE (Dynamic Data Exchange) facility.

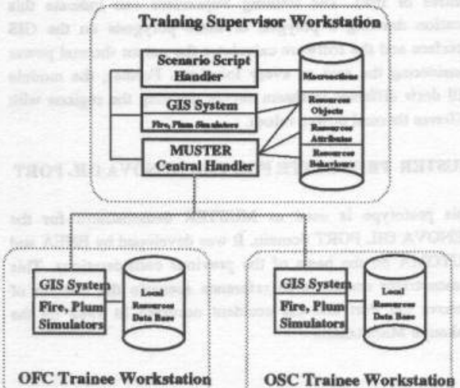

Fig. 1 - Italian MUSTER prototype configuration

The GIS system

Every trainee and the training Supervisor utilizes a GIS system for the visualization of domain layout, resources and scenario. The trainees utilize the GIS system also to execute actions on the resource objects.

The Muster Handler

As we said, during a training session the trainee must perform actions (using the resources layer objects) in order to avoid emergency propagation and to reduce damages to people, things etc. A trainee can also send messages to other trainees, can allocate resources etc.

Most of these actions require a certain time to be executed in reality. In fact, to move a tug-boat from a point inside the oil port to another point, the tug-boat needs some time available depending from the distance between the points and also other factors. To take in account these constraints the system utilizes a central module called MUSTER HANDLER. This HANDLER has two main tasks: the first one is to mantain the congruity of a central Database including all types of data regarding the different trainees' resources and actions; the second one is to control the response of actions requiring a certain time to be executed. When a trainee perform an action moving a resource from a point to another point (for example a tug-boat) the HANDLER calculates the necessary time to execute the action. The tug-boat will be displayed on the arrival point only after the handler internal clock will have counted the necessary time.

The Scenario Script Handler

As mentioned above a training session involves a training Supervisor and some trainees. The Supervisor is granted all accesses to the hardware and software resources for the training program. He has the complete control of all elements of the scenery under consideration. He can manages the resources, can insert new events in the current scenario, and, if deemed advisable, he can vary the number of resources available, the conditions of their utilization, of their accessibility and availability, the operating time, the general and particular weather conditions.

The scenario script handler gives support to the training Supervisor in the task of monitoring and control the trainees' behaviour. Using the Handler the Supervisor can visualize the planned scenarios and events, the trainees expected and executed actions. He also can start/stop the training session, invke/disable the trainees' actions, visualize/start next scenarios etc.

The Scenario Tree

The system also supports the Supervisor during the phase of session planning to generate session scripts (*Larsen et al.1995*). A session script can be conceptually viewed as a tree composed by nodes and arcs connecting different nodes as visualized in fig.2. It is used by the Scenario Generator as a scenario tree where every node corresponds to a domain scenario, formed by the mapping of the different layers as previous defined. Every arc corresponds to the set of actions that the trainee must execute to generate the n+1 scenario from the n scenario. So, the n+1 scenario may be seen as an updated status of the n scenario. The set of actions may be normally executed by one or more trainees so that they can be named composite actions or *macro actions*. The new generated scenario implements in the resource layer the updating (changing of state) caused by the macro action and, eventually, in the scenario layer the updating caused by the insertion of new physical events that may be preplanned into the script or inserted on-line by the Supervisor.

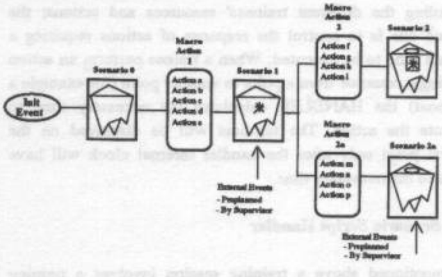

Fig. 2 - The structure of the generic Scenario Tree

In the actual prototype the planning phase will not be demonstrated. So the prototype will have an already designed script that corresponds to the Hakouyu Maru accident (*Casablanca and Meta 1982*) history with some alternatives (different arcs at some nodes) in a set of defined point inside the history itself.

Macroactions

As described above, a *macro action* is the set of all elementary expected actions generating a new scenario from the old one. To explain more deeply this concept it is necessary to give a more detailed definition of an action. An action may be described at different levels of accuracy: in fact we can say that during the emergency the on-field coordinator performs the action to allocate the Fire Brigades motortanks near the fire locations, without establishing the precise locations for every motortank or the exact number of motortanks: these are in fact more specific information associated to the generic action of motortanks allocation.

To face the fire, the agent must surely execute the more generic part of the action (allocating motortanks) but he can execute the more specific part of the action in many ways and the action results may be acceptable or not respect to an higher or lower degree of evaluation. During the execution phase the system *controls* only the generic part of the action, the specific part is only *monitored* on the training Supervisor screen.

The control and the evaluation of the specific part is done by the Training Supervisor itself.

Events

In the passage from an old scenario to a new one may be also involved external physical events like fires, explosions ect.. The events can be predetermined in the planning phase by the training supervisor or inserted on line during the execution phase. Evolutions of the physical events may be also illustrated with the support of external simulators.

The External Simulators

The MUSTER system utilizes also external simulators to furnish data about the effects of the accident releases. In the Italian Muster prototype simulators of fires (calculating the air temperature distributions) and of smoke column dispersion was implemented. To calculate the fire's power the simulator needs the fire location (or the fire locations if there are more centres of fire). The training Supervisor can indicate this location drawing a polygon or more polygons on the GIS interface and the software calculates the output thermal power considering the area of every locations. Further, the module will draw different isotherm curves dividing the regions with different thermal power values.

MUSTER PROTOTYPE FOR THE GENOVA OIL PORT

This prototype is used as MUSTER demonstrator for the GENOVA OIL PORT domain. It was developed by ENEA and AUTOMA on the basis of the previous considerations. This demonstrator considers as reference scenario the domain of Genova Oil Port and the accident occurred in 1982 on the Hakouyu Maru tanker.

The formalization of the selected accident

In fig. 3 we can see the formalization of the scenario tree used for the Italian MUSTER prototype training session. As it is evidenced from the figure there is a right path of the accident evolutions and some wrong paths. Wrong paths may be initiated from wrong trainees' decisions at some critical points: for instance in the Macro Action 3 there is the Port Evacuation action. Really this was a very important action.

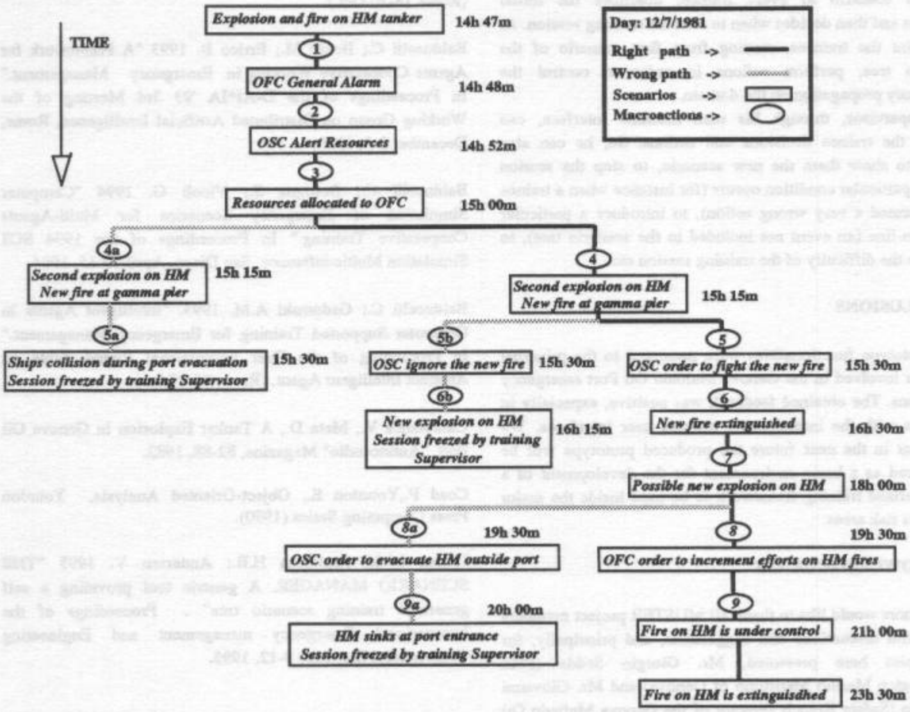

Fig. 3 - The Hakouyu Maru accident scenario Tree

Together with this action the responsible trainee (the Oil Port Director) must indicate the right order of the ships evacuation. If this order is wrong the possibility of ships collisions arises and the training session will be stopped (freezed by Supervisor) as indicated in the scenario tree after the Macro action 5A.

Involved Trainees

The considered domain in the demonstrator has been defined as ON-SITE domain. All the territory outside this domain is the OFF-SITE domain. We have assumed that this accident involved only the ON-SITE domain, so the first trainee is the ON-SITE coordinator (the Genova Oil Port Director).

The ON-FIELD coordinator, the second trainee considered for the demonstrator, manages the operations near the accident location supported by the Fire Brigade Chief. All other trainees are simulated. It means that they can receive but not send messages and that their actions are simulated by the system or by the training Supervisor himself. The training Supervisor, that conducts the training session from his own workstation, is the third agent in the Genova Oil Port Demonstrator.

The trainees can execute operations on the simulated scenario: they can send messages to each other or to simulated trainees, they can allocate resources or decide ON-SITE/ON-FIELD operations (like the port evacuation, event notifications etc.).
The Supervisor, at the begin of the training session, shows the accident scenario to every trainee, describes the initial situation and then decides when to start the training session. At this point the trainees, starting from first scenario of the scenario tree, perform actions in order to control the emergency propagation on the domain.
The Supervisor, through his man machine interface, can control the trainee decisions and actions. So, he can also decide to show them the new scenario, to stop the session when a particular condition occurs (for instance when a trainee has executed a very wrong action), to introduce a particular event on-line (an event not included in the scenario tree), to increase the difficulty of the training session etc.

CONCLUSIONS

The prototype functionalities were presented to the principal end-user involved in the Genova Multedo Oil Port emergency operations. The obtained feedback was positive, expecially in relations with the implemented trainees user interfaces. We hope that in the next future the produced prototype will be considered as a basic environment for the development of a computerized training framework to be used inside the major Oil Ports risk areas.

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Emergency Management Training Systems Using Virtual Reality

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VIRTUAL REALITY FOR EMERGENCY TRAINING

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ABSTRACT

Virtual reality is a sequence of scenes generated by a computer as a response to our five different senses. These senses are sight, sound, taste, touch, smell. Other senses that can be used in virtual reality include balance, pheromonal, and immunological senses. Many application areasinclude: leisure and entertainment, medicine, architecture, engineering, manufacturing, and training. Virtual reality is especially important when it is used for emergency training and management of natural disasters including earthquakes, floods, tornados and other situations which are hard to emulate. Classical training methods for these extraordinary environments lack the realistic surroundings that virtual reality can provide. In order for virtual reality to be a successful training tool the design needs to include certain aspects; such as how "real" virtual reality should be and how much fixed cost is entailed in setting up the virtual reality trainer. There are also pricing questions regarding the price per training session on virtual reality trainer, and the appropriate training time length(s).

1.0 INTRODUCTION

Virtual reality is an environment that is so realistic it actually emulates the real thing (Holbrook 1991). It has also become a buzz word with "frivolous" connotations (Adam 1993). Virtual reality is a sequence of scenes from a database of images which is determined as a response of our five senses to take us to the depths of an immersive experience. These senses are sight, sound, taste, touch, smell. Others include balance, pheromonal, and immunological senses which look promising with virtual reality. According to David Mitchell, (Mitchell 1992), the systems operator of the Diaspar VR Network BBS: "Virtual reality is the artificial stimulation of human senses and artificial response to human actions." A virtual reality system consists of a display screen, a tracking device for interactivity, a computer image generator, a three--dimensional database, and application software (see Adam 1993). It is defined in (Hayword 1993) as something like reality and almost like reality. How much like reality? 93.742% like reality? How "real" should virtual reality be? Is it a technical question, a strategic question or a marketing problem?

The scope of virtual reality is determined by how many senses are being stimulated. The first five are the ones we learned in elementary school. Balance is defined as a state of equilibrium in weight, value etc. It is felt by the ear and muscle tension. Pheromonal is communicated through scent glands and olfactory lobes. It refers to the chemical messages we transmit. Immunological sensors are lymph nodes, and mucous linings act as the transmitters. The degree to which virtual reality behaves like reality is measured by the scope and intensity of the immersive experience.

Right now balance and sight have been tried in virtual reality skiing but most senses interfaced include sight, sound and touch.

To understand virtual reality imagine you are in a booth covered with TV screens. You see Mohammed Ali. You throw a punch at him, he feels it and drops back a step. He responds with a punch and it is so real you react and go back a step. This is just the beginning. You can make the fight more active according to your choice. If you like excitement and are a risk taker, the system acts differently than if you are risk averse. How can this be done? Virtual reality measures an individual's vital signs through sensors placed on the screen and/or the gloves and adapts to the preferences of individual customers to provide maximum satisfaction.

What can virtual reality do? What are the possible application areas? All possible avenues have not been considered yet. The applications receiving the most publicity for using virtual reality are entertainment and leisure, medicine, architecture, and defense training. The leisure industry may turn out to be the biggest user. For example, a skier can put on a helmet and gloves and start skiing through the trees. If you are not interested in the trees, you can opt for wide open spaces. If you get too tired, you can take a nice and easy, relaxing run. (Thornton 1993), in a recent Fortune magazine article reports that there are no plans to provide the sensation of broken limbs. However, users can preselect the difficulty which allows a maximum speed of 25 miles per hour, and jumps of up to 33 feet high. Depending on your choice, if your pulse gets too high, the system eases up and flattens moguls or bumps at signs of excessive stress depending on the personal choice.

Other applications of virtual reality include medical students studying to be surgeons. They can put on a helmet and gloves to operate on a virtual patient. Architects can use virtual reality to design a building and walk through it before they actually build it. Engineers can design products and analyze them without going through the expensive steps of manufacturing. Pilots can fly planes without leaving the ground and land at the most difficult airports. Students can learn to drive. It is a very effective learning tool, as per the old Chinese proverb "hear and forget, see and remember, do and understand" as stated in (Theasby 1992).

Researchers at British Telecommunications are developing a network design and management tool based on virtual reality. Caterpillar Inc. is using virtual reality to engineer its earth moving equipment. Still other uses include auto design, molecular modeling, animation design. Chrysler and IBM are working on virtual cars. Boeing is developing a virtual airplane. The Pentagon has plans to experiment with wall-to-wall supercomputers powerful enough to grind out more-realistic virtual realities. Miller Brewing Company has used virtual reality in the annual National Restaurant Association Conference in Chicago (1993) to promote its products. Virtual reality even has sex appeal with virtual sex, which as Newstrack (1993) states "should give Madonna enough fodder for a literary sequel."

Virtual reality can do all sorts of things, but at what cost? W Industries based in Leicester, England has machines that allow virtual reality to work, costing up to $120,000. NEC calculated their own machines should sell for $100,000 before they can realize a profit. Michael F. Deering, a senior staff engineer in Sun's virtual reality group, notes "... a virtual reality experience at the right price will sell." The price of virtual reality machines will of course, have a significant input on the price of the virtual reality experience. A key question that we address in the paper is: how should the price of virtual reality training experience be determined? We also ask whether virtual reality trainer should complement or substitute other training systems. This will most likely depend on the individual and the application. Can we distinguish individuals who perceive virtual reality training as a substitute from those who view it as a complement of other training systems? Are the virtual reality training companies likely to merge with other training system companies? Can we expect strategic alliances between virtual reality trainers and other training system providers?

The rest of the paper is organized as follows: Section two describes selected issues in virtual reality design. Section three is the overview of the suggested pricing schemes for virtual reality in the entertainment industry. Section 4.1 considers surgeon interns' education as an illustrative case for the emergency training. It highlights the similarities and differences between the entertainment industry and surgeon education. Section 4.2 looks at the other situations for emergency training with virtual reality. Section 4.3 summarizes the advantages and disadvantages of virtual reality training systems. The final section contains our concluding comments.

2.0 DESIGN OF VIRTUAL REALITY PRODUCTS

The formulation of individual virtual reality product attributestypically assumes a discrete system of a ten point scale, with each point further divided into five sub-categories: excellent, very good, good, fair, poor. For example, a sight including 256 colors may be regarded as excellent by some. Most individuals may regard normal black and white as poor while black and white with 12 shades of gray may be considered as fair. Not every individual has the same value system. Heavy metal rock band Guns and Roses' lead singer Axel Rose may think 100 decibel sound is excellent while comedian George Burns may regard it as poor.

Another attribute could be the camera angles. This is extremely important in sporting events. One may like to watch a football game at the 50 yard line, in the middle of the stands. Someone else might prefer a location with a closer view of the coach. The French Open tennis tournament camera angles cover more flesh -- especially the female players -- while those angles may not be appropriate in the US Open. For a virtual reality trainer some might prefer a camera angle from the point of view of the rescue operator, while others opt for overlooking angle. Sight and sound might be less appealing to some than balance and pheromonal. The foregoing classification does not include interaction between the different senses. Combinations of senses taken out of eight senses have to be considered as different stages.

Consumers are heterogeneous in their preferences. Different people like (dislike) different things. How are virtual reality designers going to determine which frame to show next, under what conditions? How much of an immersive experience is going to be provided in the first, second, third, or the nth trial? What is going to attract the trainee to the virtual reality trainer.

In a movie advertisement, five minutes of scenes are shown to attract the movie goer to come and see the movie. Climactic scenes are shown without the climax itself. Some movies also have sequels. Soap operas continue for years according to the audience response.

Selected issues in the design of virtual reality products include:

- What is the total capability of the system?
- What should the first experience and the subsequent experiences be?
- Is the whole system fixed or ever changing? How does the experience adapt to user response as measured on the eight senses?
- Does virtual reality trainer complement or substitute the other training systems?
- How much fixed cost is entailed in setting up for offering of virtual reality training experience?

The answers to some of the questions might be industry and/or individual dependent. If that is the case, then a dynamic model which changes according to the individual and/or the industry needs to be developed.

3.0 PRICING OF VIRTUAL REALITY IN ENTERTAINMENT INDUSTRY

According to (Altinkemer and Kalwani 1994a) the pricing currently used on virtual reality are fixed rate, per unit time and two part pricing. These pricing schemes are suggested to maximize the profits by offering maximum satisfaction making the user come back for subsequent experiences. Differentiation can be used to further increase the profits. This is illustrated in skiing based on the level of skier, snow conditions, difficulty level of slopes, and a combination of above features. Others include seasons and the location of the virtual reality. The winter season may treat virtual reality skiing as a complement. During summers one may charge high prices as they can be considered as substitutes. Location could change whether virtual reality skiing is treated as substitute or complement. In Aspen where you are close to the ski resort treat it as a complement and in New York City where you are not close to a ski resort treat it as a substitute.

Dynamic precision pricing is introduced for virtual reality. Every users' experience is somewhat different than other users'. This aspect of virtual reality allows the implementation of dynamic precision pricing. This price is a function of service quality, attributes of the application, amount of time spent in virtual reality, level the user terminates virtual reality, and system reaction lag. Increasing the system reaction time lag decreases the price. Other considerations increase the price if their level are increased.

(Altinkemer and Kalwani 1994b) suggest in creating a product like virtual reality there are challenges in designing and pricing. It states pricing involves short term and long term pricing. In the long term, the potential interaction in the demand for virtual reality experience with that of the use or consumption of reality is considered. In this case virtual reality is viewed as the precision product that satisfies an individual's tastes. For an optimal pricing strategy, a long term diffusion rate has to be considered. Analysis shows that an integrated monopolist should charge differently than the two independent firms providing virtual reality and reality. It is suggested that whether reality or virtual reality is seen as the contingent product may vary with the individual customer.

4.0 TRAINING

Under this section we look at surgeon education and emergency training. Advantages and disadvantages of virtual reality education are given in section 4.3.

4.1 Surgeon Education

Surgeon education has quite different characteristics of its own compared to the entertainment industry. This is assuming virtual reality where all senses are interfaced. Surgeon interns will be able to get a time slot on the machine and learn interactively at their own pace with the gentle guidance from virtual reality. First, all possible scenarios need to be programmed. In order to put bells, whistles with different twists and angles, many endings and different procedures need to be programmed. Once a complete virtual reality training system is available it will require a learning model to implement virtual reality.

Currently, there is experiential learning. The learning environment enhances participants involvement in some kind of personally meaningful activity. Virtual reality provide interactive fully immersed participation where the participant applies some knowledge of theory and principles which results in accomplishments or failure. Virtual reality will select a path tailored to individual tastes to enhance learning. In order to bring a change in attitudes, behavior and knowledge, often a four state learning model, is referenced in (Keys and Wolfe 1990).

Concrete Experience → Observation and Reflection → Formation of Abstract Concepts and Generalization →

Testing Implications of Concepts in New Situations.

The impact of learning is the greatest when

(i) it is accompanied by an optimal amount of emotional arousal,
(ii) it occurs on safe grounds,
(iii) it allows adequate processing time and a summary pointing and emphasizing the moral of the story.

Others advocate "integrative learning" which emphasizes learning from differences in content, point of view, and learning style with an open ended approach. Integrative learning is similar to "double loop learning" which is based on informed decisions and internal commitment described in (Keys and Wolfe 1990). The learning grid divides the learning process into content, experience and feedback. All three parts need to be developed for positive, useful, and fully immersed learning exercises.

There does not need to be a superior way or a method. All these methods can be embedded in virtual reality. In fact if a new learning model is developed at a later date one can add to the model, and virtual reality will teach the subject according to the new method.

4.2 Emergency Training

There are natural disasters such as hurricanes, tornados, floods, earthquakes, mud slides, volcanic eruptions, forest fires, avalanches. These are activities where efficient fighting methods are very important, and they have enormous effect on the course of events.

These disasters have been fought by highly skilled people who have been trained with classical methods. One of the limitations of such approaches is that one cannot emulate all possible scenarios. Hence, some of the training is performed during the actual disasters which because of the lack of experience can cause injuries, even loss of lives. Experience can be an expensive teacher. However with virtual reality all of these scenarios can be covered at a smaller cost of physical material and human lives.

Another area that can be appropriate to virtual reality is technological disasters. These include urban fires, chemical and nuclear spills, plant accidents, transportation accidents, 911 cases, telecommunication failures, utilities failures, and environmental emergencies. Training for wars, terrorism, and riots are more human response dependent. An action of a rescue worker might decide the success of the whole operation. Again in these situations common sense may not be used because they are not obvious. When fires and violence took place in Los Angeles, on April 29, 1992, it was evident that plans to handle such events were totally inadequate. The Building Emergency Leaders (BEL) SYSTEM mentioned in (Oliver 1993) helps better equipped professionals for emergency situations. (Andrus 1992) mentions an emergency backup system which is also used as an operator training facility. Virtual reality will take it leaps and bounds ahead of these simulators and make such uncommon events a part of everyday life. It will be the perfect trainer for the unexpected.

There is a question of how to price such training sessions. First of all, a twenty-four hour day needs to be divided into reasonable length time slots. For this the optimal length of a training session needs to be determined. Then, the day can be divided from the highest use to lowest use. Trainees can bid on the time slots for training. The bidding needs to be closed a few hours before the actual time slot. The time slots can take bids from stand-by trainees. These measures do not have to be absolute. The system can learn by experimenting and establishing an optimal strategy.

The other unresolved issue is whether a virtual reality trainer substitutes or complements other types of training systems. What would be the functions of a teacher who has been teaching in a conventional training system? Will the teacher be a consultant or a competitor of the virtual reality trainer?

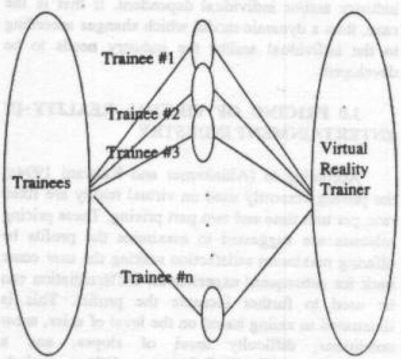

Figure 1. Virtual Reality Trainer

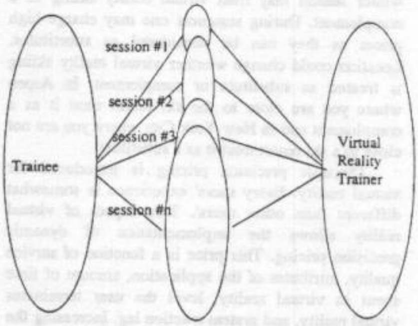

Figure 2. Training Sessions

The virtual reality trainer offers a precision training session for the trainee (see Figure 1). According to their ability and the knowledge, each trainee can have a unique training experience. The trainee can have custom-fit training by choosing the teaching method, camera angles, level of feedback, number of senses involved, and which senses are required. For example, a fire fighter may initially choose an experience without high temperature. This component might be added for later experiences. As training progresses, sessions get complicated and more comprehensive. Figure 2 depicts this phenomenon.

Virtual reality could be also used as the perfect feedback. It could keep track of the trainee's performance over a training period and it could highlight the perfect finishes, performance under stress, improvement over time. This information can be used to place the trainee for a certain position.

Another possibility is to have different functions of a virtual reality trainer. One of them is the training function, the other is the grading or performance evaluation function. If traditional methods are preferred these functions can be done separately. This would be similar to the conventional teaching methods. Have teaching and exams separately. If you want to have total quality grading, every response during one's learning period is valuable. This continuous grading mechanism could also be achieved with virtual reality trainer. This could be called incremental or total quality learning and performance evaluation.

4.3 Advantages And Disadvantages Of Virtual Reality Training

What are the advantages and disadvantages? About 500 years ago, Leonardo da Vinci sketched the first airplane. The reason people could not materialize the idea was that necessary tools were not yet built - not because it was a wild idea. The Wright Brothers built a plane by being at the right time and the right place. Right now we have the concept and virtual reality where only three senses interfaced (namely sight, sound and touch). We have a long way to go. How far and how fast we approach virtual reality will play an important role with benefits and disadvantages.

Let's assume perfect virtual reality where all senses are interfaced. One of the benefits of virtual reality is reliability. Virtual reality does not become tired, bored or sick. It does not go on a strike, and it does not argue with the boss. Most importantly, it will notice the slightest errors and perfect finishes. This will help it furnish the perfect feedback.

We can draw an analogy to Expert Systems (ES). ES can function better than the expert which the system is built upon because of factors such as not having a headache. ES may operate better because expertise might be collected from more than one expert. Because of the synergy of knowledge they might out perform the human expert. These may be some of the benefits of virtual reality as well.

Other benefits include a point system which would help surgeons or emergency trainees find their true market value. This point system could be a benefit because a computerized system virtual reality could match the performance to a score system which gives a generalized score (like GRE, GMAT). Another benefit could be that surgeons would be on a more equal playing field - it would not matter whether you received the training from University of Nebraska Medical School or John Hopkins Medical School. The precision and teaching ability might not be dependent on the prestige of the school.

The disadvantages may come from the technology. If certain aspects are not realized it will not be able to emulate reality. We assume given time, virtual reality will be perfected. Another factor is that an intern using virtual reality may subconsciously know that it is not real and can feel more relaxed and perform better surgery. Under real conditions the pressure of reality might cause more mistakes and degrade the performance. This is a possible disadvantage, but by using the point system mentioned above, real-life pressure could be emulated. If interns perform unsatisfactory operations they receive fewer points, which in turn will affect their market value.

In terms of a grading scheme, a surgeon intern with perfect finishes since the first virtual reality experience maybe clearly superior to others. However, one who improved to be a perfect finisher in x trials versus y trials does not imply dominance relationship even $x<y$. A grading scheme like GRE, GMAT national tests on different areas such as quantitative, verbal, analytical or specific subjects like biology, could be used. This system will allow surgeon interns to specialize on certain aspects and certain surgeries. If one is not precise, one should not choose to be a surgeon using lasers for prostate surgery.

There are other issues, such as the long-term capacity planning problem and the short-term resource allocation problem. The two problems are tied to each other. In order to decide on the long-term problem, one might look at the number of full time equivalent teacher hours that will be available. Another component is the productivity and efficiency gain or loss due to a virtual reality switch. A surgeon educator might end up doing more surgery or research or clinical care and the educator might do better or worse in those tasks depending on their background and combination of tasks. This also holds true for the emergency training.

The short-term problem is equivalent to assigning time slots to surgeon students or emergency trainees. Alvin Roth has studied in a series of papers the two-sided matching problem which he concluded in a book by (Roth and Sotomayer 1990). The problem deals with how men and women are matched to each other when they reveal their preferences about the other sex. The problem has been applied to sorority rush, assigning interns to hospitals, and the college admission problem.

We need a mechanism which leads to revelation of true preferences on time slots. Certain time slots will be in more demand than others. Students might bid on time slots and the system might place students on the time slots based on their preferences and system optimum.

There are different problems and challenges from the entertainment industry to surgeon interns' education and emergency training. At least one issue remains the same: Is virtual reality training a substitute or a complement of the real thing? The answer to this question may make the difference in pricing the activity and may help engineer the design of virtual reality.

6.0 CONCLUSION

Virtual reality has many application areas such as leisure and entertainment, medicine, architecture, engineering, manufacturing, and training. Since it is a totally new product with attributes unlike any other existing products, its design and pricing are challenging problems.

Surgeon educator or emergency trainer virtual reality, on the other hand, is totally different than use within the entertainment industry. First of all, it has to be based on a learning model. Students can choose from many available models. Benefits of virtual reality in this area are similar to the benefits of expert systems. Virtual reality educators do not sleep, get sick, have a down day etc. implying better performance with zero variability for every experience. New benefits include the effect of virtual reality on the school's name, and a point system which may help establish a surgeon's or emergency trainee's true market value.

The common issue is whether virtual reality trainers and conventional training systems are complements or substitutes. The composition of the clientele, whether naive or sophisticated may govern who will be trained in which system. Being a complement or a substitute may affect the pricing strategy and the design method.

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EMERGENCY MANAGEMENT TRAINING: USING A VIRTUAL REALITY REPRESENTATION OF THE DISASTER SITE TO TRAIN SITE DECISION MAKERS

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ABSTRACT

The application described in this paper is partly a stand-alone application and partly one of the modules of the MUSTER system (Multi-User System for Training Emergency Response). The system architecture and its modules are described in accompanying papers published in the TIEMEC '95 Proceedings (V. Andersen & HB Andersen, 1995, contains and overview of the MUSTER system, while details about specific modules, configurations and aspects of target scenarios are described in Balducelli et al., 1995, and in HB Andersen et al. 1995). In the paper we discuss some of the reasons why visual input is of particular importance to trainees who play the role of site decision makers.

Introduction

The visual features of a training environment may in some cases be crucial to the success of training whereas they will play a negligible role in others. For instance, when a pilot is trained in a full flight simulator which incorporates a state-of-the-art visual system, the training providers have spent several million dollars on just the visual system alone. They have done so, of course, precisely because there is reason to believe that pilots would not acquire - at least not nearly as efficiently, safely or as comprehensively as they do - the type of flight skills and knowledge they need if they are trained in simulators having more primitive visual systems. In contrast, when pilots learn pre-start check procedures, they need no visual system representing the world outside the cockpit. Consequently, to save costly lessons in the expensive full flight simulators such procedures training is often carried out in simulators which, developed at much more modest costs, have no visual (or motion) system.

Similar remarks could be made for a range of other domains involving real time control of safety critical systems or processes. Thus, for instance, anaesthetists are, in certain hospitals, trained to cope with rare but serious incidents by being exposed to two kinds of training environments (along with their on-the-job training in operating theatres during real anaesthesias provided by instructor-doctors). One kind of training environment involves a full-scale anaesthesia trainer comprising a mannequin (the 'patient') and all the usual anaesthesia equipment and instruments linked up with a simulation of the reactions of the anaesthetised 'patient'. (Gaba and DeAnda, 1988; Jensen *et al*. 1993). Another training environment is provided in a reduced and much less costly form by a stand-alone PC-based simulator. The latter, which runs underlying simulations which are similar to those of the full-scale simulator, provides feedback to the trainee only via a single computer screen and possibly auditory alarms (Schwid 1997). Now, the small-scale, PC-based simulator is a useful training system and it is, compared with the full-scale simulator, a quite sufficient training system for certain training purposes, namely the training of procedures and sequential condition-action steps. Where it is lacking is in providing trainees with clinical cues from the patient/mannequin and the various types of anaesthesia equipment and, very importantly, social interaction cues. So, the full-scale simulator is needed for training anaesthetists in developing good co-ordination skills and, in general, skills in handling incidents as a team. (Gaba *et al.* 1994; Jensen *et al.* 1993). In general, therefore, when designing training simulation environments the designers involved need to consider that certain tasks or job roles require, and certain others do not, that the operators and decision makers involved receive a relatively rich and dynamically updated visual feedback from the domain of operation.

Visual representation of site scenery in emergency management training

When considering the needs for training support for emergency management tasks, there is a distinction to be made in terms of the visual feedback required. Thus, without going into detail in analysing in general terms the differences between the tasks for which rich, dynamic feedback is necessary and those for which it is not, let us just note that there is an obvious distinction to be made between 'site' trainees and 'off-site' trainees. Thus, the requirements to visual representation are very different for these two types of trainees: there are on the one hand, trainees who, during real emergencies, will have available and who will exploit their view of the *site of emergency* and, on the other, trainees, usually placed in remote control centres, who will not have any such possibilities. It should be noted, however, that for the latter category, it will may well be the case that updated visual input will play a essential role for their ability to fulfil their tasks. Consider, for instance, emergencies involving - as in the case of the target applications of the MUSTER system - responses by personnel at remote centres controlling train traffic or harbour traffic. Among the staff of control centres, typically located some distance away from the site of the emergency, are people who rely essentially on control systems that provide graphic or character-based information and overviews, say, a display of the location and movements of trains. Hence, in order to provide a training environment with a suitable degree of realism, such trainees need to have some kind of simulated overview of the virtual trains in the virtual scenario.

However, it is in general more difficult to satisfy, in regard of visual representations of the virtual events taking place in the training scenario, the needs of *site trainees* than the needs *off-site trainees*. The site trainees in the MUSTER applications are decision makers involved in deploying, say, fire fighting units and ambulance crews. For the railway accident scenario that has been chosen as the MUSTER demonstration case a goods train carrying dangerous cargo has been derailed and several wagons have been overturned. At the same time, the surrounding terrain contains neighbouring tracks and steep slopes and brushes. It will be difficult to provide the chief decision makers, the Fire Brigade Chief and the Railway Emergency Manager, the Police and Ambulance Site Chiefs, with the right amount of information. Giving them a map, perhaps a dynamically updated map as contained in a GIS system, will tell them too much and too little. Too much because objects which would be occluded at certain angles of sight will be visible on a GIS or map representation; and too little because it is difficult to indicate on a map, without revealing the desired solutions, the suitable routes of approach, etc.

At the early stages of the MUSTER system design it was recognised among the project partners that some form of dynamic visual feedback had to be provided to field trainees; but no firm decision was made as to the way to provide such a feedback. Several ideas were discussed, including setting up a 'Lego'-table in the training supervisor's room and letting trainees have a video-view by way of pen-sized cameras from the Lego-world. According to this concept, the location of the virtual objects - which would be represented by toy train wagons, trees, tracks etc. would be recorded in a database and the movements of movable objects (resources) would be changed according to trainees' instructions. As an alternative it was discussed to have the movable objects on such a 'Lego' table (fire units, wounded people, train wagons etc.) be electronically marked so that, although moved by hand, their locations might be logged electronically.

Nevertheless, it was agreed among project partners that in the context of the MUSTER system, which incorporates simulations of physical processes and a database in which will be logged resource allocations, the optimal solution to the challenge of providing a visual representation of the site would be to create a virtual reality representation of the site so that the representation could be dynamically linked with *(a)* the physical processes being simulated (fire, smoke and toxic release plumes) and *(b)* the movable objects involved (resources and wounded people). In the following we describe the VR application and its links to the other modules of the MUSTER system.

Virtual Reality terminology

Virtual Reality (*VR*) is an emerging technology, and the definition of what it really is has been widely discussed. As the phrase indicates, the purpose of a VR applications is to simulate the real world, and the final goal is to accomplish this so well that the user cannot tell the difference (confer for instance Kalawsky, 1993). However, today's technology is far away from that goal and we will describe today's standards.

The creation of 3D (virtual) worlds and pre-calculated animation of objects in such worlds falls under the heading of 3D computer graphics - as has been the case for many years and long before VR became known. The distinction between 3D graphics and Virtual Reality can be drawn when the user's exploration of the 3D graphics becomes interactive, that is, when the user can change his/her viewpoint in the 3D world *in real time*, thus simulating that (s)he moves around in the artificial world. Such a movement can for instance be a walk or a drive in a car or a flight in an aircraft.

The main subclasses of the VR concept are *immersive* and *non-immersive*.

Immersive VR entails that the users' senses are (largely) confined to input from the virtual world. This is typically accomplished with a Head Mounted Display (HMD) which to some degree permits the wearer to see stereoscopic 3D graphics and hear artificial sound from the virtual world, and where head movements also change the viewpoint in the 3D graphics. Often this is combined with a glove, giving the user an artificial hand which (s)he can see in the HMD and move and even interact with objects. This gives the user an impression of actually being inside the virtual world.

Non-immersive VR, in contrast, gives the user an impression of moving a *camera*. The 3D graphics are typically displayed on an ordinary (large) screen. There are of course in-betweens, where a glove is combined with on-screen graphics etc. *Desktop* VR is a non-immersive solution where the user moves and interacts with virtual objects through a standard (2D) mouse or the keyboard, and graphics and sound are output to a screen and to loudspeakers, respectively. (See Kalawsky, 1993, and Loeffler & Anderson, 1994, for descriptions of the technologies involved).

Characterization of the MUSTER VR environment

For the MUSTER project we have chosen a non-immersive desktop VR approach. The choice was based on selected real-world aspects of rail-road (and harbour) emergency management. First of all, it has been regarded as important for the achievement of good training effect that site trainees are allowed to use the standard communication equipment, such as portable two-way radios, mobile telephones etc., which they are used to employing during real-world incidents. Our requirement that trainees be able to make use of their standard communication equipment made the choice of non-immersive VR natural. But, secondly, and equally important, was the consideration that current technology is incapable of generating facial movements, so that non-verbal face-to-face communication in general between trainees would be limited. Therefore immersion would be impracticable.

There will be no direct interaction with virtual objects in the prototype version of our application. Though the trainees as such will be limited in their actions, there will be objects like fire and smoke changing in the scene just as trainees will see the effects when they have commanded the movement and deployment of certain resources (fire engines). Therefore, we classify our application as a "Dynamic Walkthrough" (DW). This is on the outskirts of VR but with obvious possibilities of an expansion to real VR (see later). For the purpose of demonstrating the usefulness of VR in training for emergency management, we believe the DW will suffice. See figure 1 displaying a sample illustration from our VR environment.

Let us finally note that the trainees will control their movement around in the scenery as well as the orientation of their view by using input from a mouse or trackball or even a keyboard.

Contents of the VR scenario

We make a partition of objects in the scenery in three classes:
static objects,
dynamic animated objects and
dynamic non-animated objects.

Static objects are objects such as rail-road tracks, roads, buildings and so on, that do not change throughout the

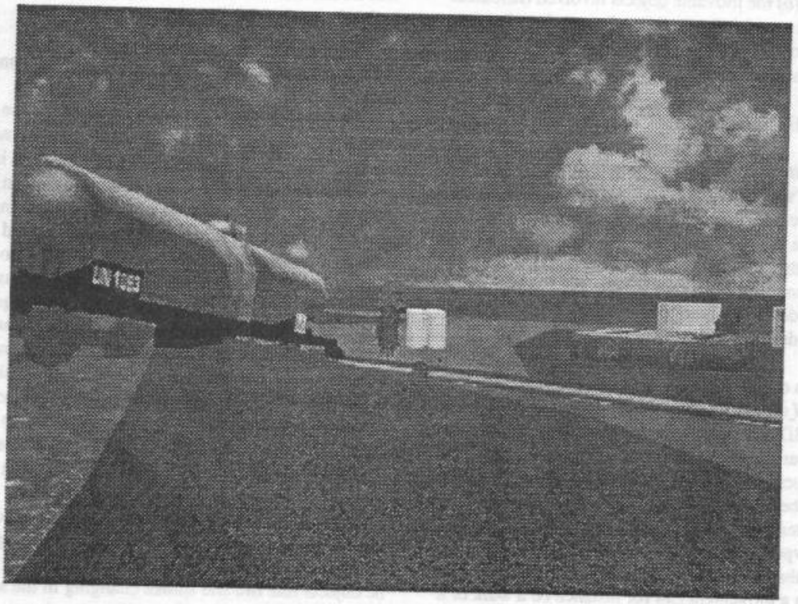

Fig. 1: Sample illustration of the MUSTER Virtual Reality environment

whole session. Dynamic animated objects include fire, smoke and visible clouds of toxic gasses. For obvious reasons these will have to be dynamic, but to give a realistic impression of e.g. fire we add animation. Dynamic non-animated objects are dynamic objects that we felt tempted to animate, but where we fear that animation will add a unsuitable and illusion-thwarting 'computer game effect'. These include fire engines, ambulances and people. They will be inserted on/removed from their changeable locations by a screen refresh when needed.

In one version of the prototype we display some types of crucial information to trainees which they would be getting in a real-world situation from senses other than vision. They include messages telling the trainees that in their current (virtual) location it is "very hot", "air is stifling", " strong acidic smell"; but we are experimenting with ways in which to convey these types of information. Finally, sounds stemming from fire and sirens are reproduced via a sound card and their production linked to appropriate stages of the scenario.

Connections and communication

Apart from the visual representation all communication to and from the VR part of the application runs through the VR database (VRd).

The VRd is a 3D-grid model of the scenario space. The VRd receives and maintains information about placement and behavior of dynamic objects and the placement and orientation of the trainees. It receives information from the Process-data module in an ASCII-file, in 6 tuple format: (o, x, y, z, d, w) where o = object type (smoke, fire, gas), (x, y, z) = placement, d = degree of dispersion and w = direction of wind. The update of VRd is non-continuos in contrast to the real-time change in view-point, that is every one or two minutes VRd receives a new tuple and if the changes concern objects in the field of view of the trainee, the visual representation is updated.

VRd sends information in an ASCII file to the MUSTER Geographical Information System about location and visual orientation of the trainee. This is done in a 3 tuple format: (x, y, o) where (x, y) = location of the trainee and o = orientation angle. This is done to make the exact position of the trainee visible to the training supervisor on his overview screen displaying the GIS application.

Platforms

The development of the VR part of MUSTER is taking place as an integration of high-end and low-end platforms. We have designed the virtual environment using 3D-Studio on Pentium-based PC's. The model of the environment is subsequently ported to dVS on Silicon Graphics' Onyx computers to create the final VR application. Following this approach, we get a highly realistic scenery with almost real-time movement, as mentioned earlier.

Future developments

There are several possibilities and interesting opportunities for stretching the use of VR in training beyond what we have been presenting here. One of the problems mentioned earlier with immersion, namely tacit or non-verbal communication, might possibly be solved by using see-through HMD´s. If so, immersion would become a viable solution and trainees could meet and communicate face-to-face in the virtual environment. Different kinds of training could be performed with the same equipment by just changing the set-up and simulation program. Indeed, we might add teleconferencing and then trainees would not even have to travel to the training site.

For further details about this application readers are referred to Østergaard et al., forthcoming.

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TIEMEC '95

Planning and Evaluation of Emergency Management Training Systems

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Risoe National Laboratory

Vice Chair:
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USING A FRAMEWORK FOR CO-ORDINATED DECISION-MAKING IN EMERGENCY MANAGEMENT TO ASSESS MULTI-USER SIMULATORS

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KEYWORDS: co-ordination, decision-making, simulator, training, evaluation.

ABSTRACT

To assess multi-user training and evaluation simulators, a framework for characterising co-ordination between emergency management (EM) decision-makers is required. The framework presented here concerns decision-making undertaken by individuals within a workgroup. Co-ordinated decision-making requires each decision-maker to consider, and intervene in, the emergency domain *and* the EM workgroup in parallel. Each stream of consideration comprises mental representations with shorter- and longer-term horizons. Decision-making within a given horizon comprises a cycle of perception, assessment, decision and action. Use of the framework to assess multi-user EM simulators is illustrated.

INTRODUCTION

With the spread of flexible, multi-user simulators for emergency management (EM), there are increasing opportunities to train co-ordination between EM decision-makers, and to evaluate an organisation's preparedness to support such co-ordination. To assess the effectiveness of such simulators, a view of the task that session supervisors and scenario writers use them to perform is required. This paper characterises this task as simulation - generating and recording co-ordination issues. In the paper, an initial framework for characterising co-ordination issues in EM is presented. Use of the framework to assess multi-user simulators is then illustrated.

GENERATING AND RECORDING CO-ORDINATION ISSUES

Certain training methods and preparedness evaluation methods specify a common task - the generation and recording of co-ordination issues. An *issue*, here*, refers to a highly selective, special purpose model of the mutual influence of an interactive EM workgroup and an emergency domain (see next section). Generating issues refers to the elicitation and exhibition of such interaction and mutual influence. Recording issues refers to accumulating 'raw data' about such interaction and mutual influence in a retrievable form. Many training methods, both specific to EM and to learning more widely, implicate the generation and recording of issues (e.g. Wiener *et al.*, 1993). Review of issues (simulated or actual) may prompt reflection and discussion, and indicate the kind of additional knowledge or skill that is required. The number and nature of issues may indicate the level of competence acquired by a trainee. Many preparedness evaluation methods also implicate issues (e.g. Seifert and Hutchins 1992). Issues may prompt and inform diagnosis. They may also comprise a key element of evaluative statements. In sum, issues are the potentially instructive, insightful, and provocative findings that support subsequent pedagogic or evaluative activity. Consideration of a simulated or actual issue may support either training, preparedness evaluation, or both, depending upon the activities which precede, go on around, or follow, its generation and recording, and the workgroup and emergency involved. The separation and encapsulation of a common simulation task from related, purpose-specific training or evaluation tasks encourages the development of flexible simulators. Provided that a simulator generates appropriate issues, and records them in appropriate ways, a single simulator may, in principle, be

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* In the absence of a desired or expected behavioural 'norm', attribution of error may be problematic, so the less prejudicial term issue is preferred. In EM, there is frequently little or no consensus about the desired behaviour of decision-makers beyond the content of preparedness plan, and even then, the appropriate interpretation of the plan for particular emergency situations may be disputed.

used for either purpose, thus encouraging economies of scale.

To characterise the simulation task of multi-user EM simulators, it is necessary to consider in detail the type of issue to be generated and recorded - issues of co-ordination between EM decision-makers. To this end, an initial framework is presented below. This framework considers the behaviour of EM workgroups and their objectives i.e. what is done, and the human cognitive structures that support such behaviour i.e. what decision-makers think. The framework adopts a cognitive/systems perspective, rather than a social or organisational one, and continues to be refined in the light of its application.

A WORKGROUP MANAGING AN EMERGENCY

According to the framework[**], an EM workgroup comprises a set of interactive behaviours (see Figure 1). A number of decision-makers interact with each other (face-to-face and *through* technology) and with technology. These types of interaction are thought to be distinct (Heath and Luff 1991a). The intention of the EM workgroup is to change the state of EM Services in the field, and so influence the emergency domain more widely. An emergency, here, comprises Hazards and 'Protectanda' (entities to be protected). Protectanda comprise EM Services, the Natural Environment and Non-EM systems. EM Services, in turn, comprise People, Equipment and Infrastructure. For example, an EM workgroup may comprise: the on-site chiefs of the Emergency Services and the railways; their respective off-site, local controllers; their radios, telephones and fax machines; and their computer systems, such as resource data-bases and dispersion models etc. This workgroup may seek to reduce the threat posed by three hazards - toxic gas, fire and the electric power to the rail tracks - to many protectanda, including: the Fire, Ambulance and Police Services plus the emergency staff of the railway company; land, air and water resources; and the wider community and its property, such as adjacent rail and road traffic, neighbouring buildings and their occupants. The Fire Service in turn comprises field operatives, hoses, gas masks, fire trucks, etc. and their network of fire hydrants.

CO-ORDINATED MANAGEMENT DECISION-MAKING

According to the framework, emergency management decision-making is supported by two distinct sets of mental representations - one for decision-making with respect to the workgroup, the other for decision-making with respect to the emergency (see Figure 2). Representations about the workgroup or the emergency may be further distinguished according to their temporal horizon - planning representations have a longer-term horizon than execution representations. Planning and execution both comprise four types of representation - perceptions, assessments, decisions and promulgations (literally, representations for making public). Since these representations tend to be up-dated sequentially, they may referred to jointly as a 'cycle'. Thus, there are four cycles of representations - workgroup planning, workgroup execution, emergency planning and emergency execution. Planning and execution cycles are linked - assessments of the current situation may influence the gathering of longer term background (e.g. whether it is necessary to do so), and the plan output may influence the assessment of the current situation (e.g. which features of the situation are of interest). Planning and execution cycles also access, and deposit in, a common information base. This information base includes: (i) preparedness plans of various scope and level of detail, from within-Service procedures to joint-Service, total response plans; (ii) knowledge of emergency response, such as factual information about, for example, the geographic area and dangerous chemicals, together with more general models of, for example, the spread of fire, the effects of counter measures and the life-cycle of an emergency; and (iii) knowledge of EM workgroups, such as factual information about, for example, colleagues' purposes, skills, potential conflicts of interest, and dependencies upon each other, and more general models of, for example, colleagues' communication patterns, responses under pressure, and the impact of alternative workgroup configurations.

This characterisation of the mental structures that support management decision-making behaviour adapts a model of the command and control process[†] (Richards *et al.* 1985). The primary aim of the adaptation was to associate co-ordination with a distinct and additional kind of decision-making, rather than a simple, automatic 'interface'. In addition to considering and intervening in an emergency, a co-ordinated decision-maker also considers, and intervenes in, the behaviour of their colleagues. Many ethnographic studies (e.g. Heath *et al.* 1993; Heath and Luff 1991b), suggest that effective group working has many diverse and subtle characteristics. For example, effective group working may involve surrepticious monitoring of colleagues' equipment and behaviour, making one's own activities clear to possible on-lookers by the way the

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[**] The framework adapts a view of the interaction of humans with computers (originally devised to support the design of 'user-friendly' computer interfaces (Dowell & Long, 1989).

[†] The command and control process model was originally devised to support the procurement of military command systems.

activity is done, timing offers of collaboration to coincide with the natural pauses in work, gradual progression towards increasingly collaborative kinds of interaction, designing messages for many types of hearer, broadcasting potentially relevant information whilst minimising interruption, and implicitly encouraging, or explicitly directing, colleagues' behaviour. This paper assumes that such sensitivity and complexity arises from deliberate thought.

To illustrate the framework, let us consider an on-site Fire-Chief responding to a rail accident, at which there is a fire and a leak of toxic gas. With respect to emergency decision-making, on arrival, the Fire-Chief may seek to identify the contents of the rail wagons, the velocity of the wind, and the number and severity of casualties etc. (perceptions of emergency situation). He then forms a view of the dangers posed by the toxic gas and fire (assessment of emergency situation (see Figure 2.)) and decide that, for their own safety, all personnel must wear protective clothing under the plume of toxic gas (decide emergency intervention). Instructions to his men to wear such clothing, and to prevent those not wearing protective clothing from getting too close, are then passed (promulgation of emergency intervention). The Fire-Chief may also monitor the number and rate at which fire trucks are arriving and the speed with which police road blocks either side of the plume are established (perception of emergency background). Together with his assessment of the current situation, he judges that, over the longer term, the planned response is threatened by restricted access to the accident. This restricted access is a result of the combined effect of the electified rail-track and the toxic plume (assessment of emergency plan). He thus plans to turn off the electrical power to the rail-tracks first, thus relaxing the constraints on access, and then get the fire under some sort of control first (decision emergency plans). The Fire-Chief declares this plan to his aides, superiors and on-site chiefs of other EM Services (promulgations of emergency plans). The emergency plan influences future assessments of the emergency situation. For example, the Fire-Chief may be particularly sensitive to the spread of the fire, since failure to stop it spreading may require further planning.

With respect to workgroup decision-making, the Fire-Chief may perceive that the railway Depot Manager has arrived (perception of workgroup situation) but appears somewhat distressed and distracted (assessment of workgroup situation). Consequently, the Fire-Chief decides to 'keep an eye on' the Depot Manager, at least until the power is turned off (decide workgroup intervention). When the Depot Manager is close by, the Fire-Chief may say to his second-in-command (in a voice loud enough for the Depot Manager to overhear), "I'm going to check that the power has been turned-off in a few minutes, and then I'll be able to tell you whether or not the next fire truck to arrive can approach from the other side." (promulgation of workgroup directives). The Fire-Chief may also see that journalists are already arriving - the accident is convenient for the newspaper office (perception of workgroup background). Together with his assessment of the current workgroup situation, he judges that the workgroup plan is threatened by the prompt arrival of an unusually large number of journalists (assessment of workgroup plan). Consequently, the Fire-Chief decides that more police officers than usual will be required to ensure that the cordons are not breached. He also decides that a press officer will be needed on-site sooner than usual to answer journalist's questions (decision workgroup plan). The Fire-Chief may then ask the on-site police chief whether he is arranging this (promulgation of workgroup plan). The workgroup plan may influence future assessments of future workgroup situations. For example, the Fire-Chief may be particularly sensitive to the apparent workload of police officers, since excessive workload may require further planning.

USE OF THE FRAMEWORK

This framework for co-ordinated EM decision-making may be used to describe the co-ordination issues that must be/are generated and recorded in a simulation.

Let us imagine that an emergency management organisation requires a simulator that will generate and record *all* kinds of co-ordination issue. A prototype multi-user EM simulator (perhaps like the one outlined by Andersen, this volume) is demonstrated to this organisation. The scenario for the session postulates the de-railment of a goods train, which results in a number of injured people, a plume of toxic gas, and a burning wagon that threatens to cause an adjacent tanker of liquid petrochemicals to explode. The roles of local Emergency Service controllers are played by the supervisor and his aides. On-site chiefs of fire, police, public ambulance and private ambulance services are played by 'trainees'. Let us further imagine that two issues that were generated and recorded during this session.

Co-ordination Issue 1: Driving Through the Plume

En route to the rendez-vous, the fire trucks passed through the plume of toxic gas, rather than taking a less direct, but safer route. In real-life, those aboard the fire trucks would become rapidly sick, require hospitalisation and play no further part in the response. Video-tape recordings suggested that the Fire-Chief (who was notionally aboard one of the trucks at that time), had little information about the emergency, and so had no reason to assess the situation as requiring an alternative route (emergency management - execution). Similarly, he did not perceive that others in the workgroup may possess relevant information. Consequently, the Fire Chief did not intervene in the workgroup by getting the local fire service controller to relay, or go and get, information from the public or the police patrol car, who were already on-site (workgroup management - execution). It was unclear from the recordings, however, whether the Fire Chief's behaviour was attributable to his interpretation of preparedness plans (for example, who is responsible for ensuring that Fire Service personnel are not exposed to unnecessary danger), his knowledge of emergency response (for example, that goods trains may carry dangerous chemicals), or his knowledge of EM workgroups (for example, at this stage of an emergency, the police may have the good information because of their contact with the general public and ubiquitous patrol cars (Information Base).

Co-ordination Issue 2: Turning the Power Off

About half an hour into the response, the local fire controller was heard in audio-recordings to perceive that emergency personnel were moving onto the rail-tracks. He assessed that, if the electrical power was still on (and as far as he knew it was), there was a risk of electrocution from downed power cables (management of emergency - execution). In case the Fire-Chief was unaware of this concern, he decided to prompt the fire-chief by asking him whether the power had, indeed, been turned off (workgroup management - execution). It turned out that the Fire Chief knew from the outset of the emergency that the power was, indeed, off. From close contact with the railway before the session, the Fire Chief knew that, although the cables and pylons for carrying electric current were in place, the electricity network was not yet operational. The Fire Chief correctly assessed the local controller's ignorance and reassured him immediately (management of workgroup - execution).

Assessment

Let us imagine that the simulator only ever generated and captured issues such as 1 and 2, regardless of the scenario employed and the supervisor's roles[††]. Such a simulator would be limited in that: (i) it does not invoke planning representations for either the emergency response or EM workgroup; and (ii) the nature of the information base that underlies co-ordination is not always exposed. Such a simulator would be adequate for training and preparedness evaluations that wished to address only shorter-term thinking in co-ordination, such who may be able to obtain certain information. The simulator would be inadequate, however, for training and evaluating longer-term thinking, such as the expected ability of the workgroup to respond to unusual demands. Such a simulator may also require additional means of recording the reasons for decisions and the information brought to bear upon them.

FUTURE DEVELOPMENT OF THE FRAMEWORK

Our experience of using the framework suggests that additional aspects of co-ordination must be characterised in order to adequately assess multi-user EM simulators. In particular, the pattern of information exchange between EM decision-makers is not expressed. For example, the initial phase of one simulation we visited was characterised by information about the emergency situation flowing from the off-site, local controllers to their respective on-site chiefs. Later phases were characterised by a flow of information in the reverse direction - from on-site chiefs to off-site controllers. The pattern of communications is likely to be a relevant co-ordination issue for training and preparedness evaluation, but it is difficult to express concisely within the current framework. Also, the knowledge that decision-makers apply is described in too little detail. For example, the framework does not distinguish between presumed and assured knowledge, despite the fact that inappropriate presumption and the desire for confirmation have been heavily implicated in many sessions that we have observed. It is disappointing consequence of the framework that the above assessment was imprecise about the kind of knowledge that was, and was not, recorded. Future work may redress such limitations, possibly through Hierarchical Task Analysis, and/or Job Process Charts (Tainsh, 1985).

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[††] The issues described actually arose during a trial session we observed. However, these issues are not a complete or representative list of the issues which actually arose during that session. Thus, the assessment presented does not do justice to the prototype, and so the prototype remains anonymous.

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Figure 1: A Workgroup Managing an Emergency

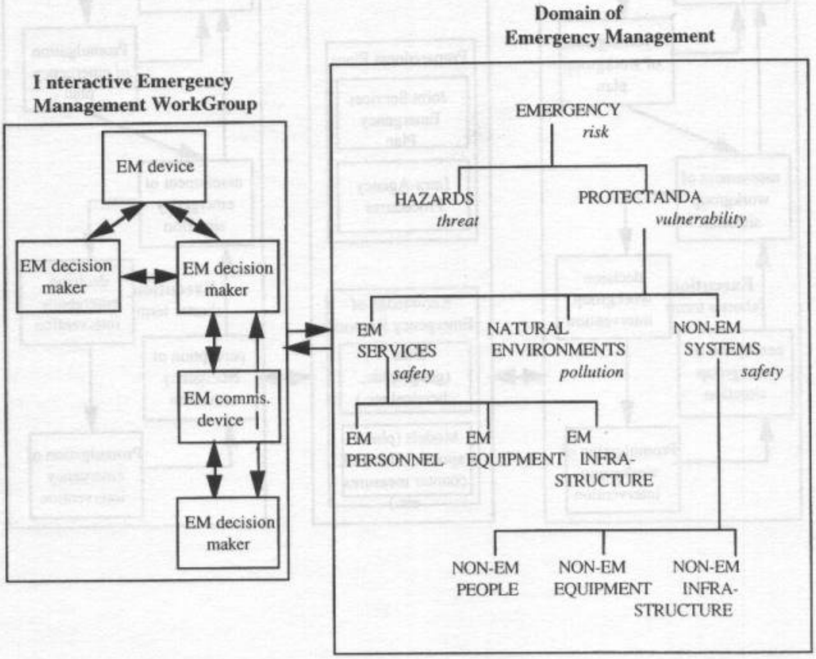
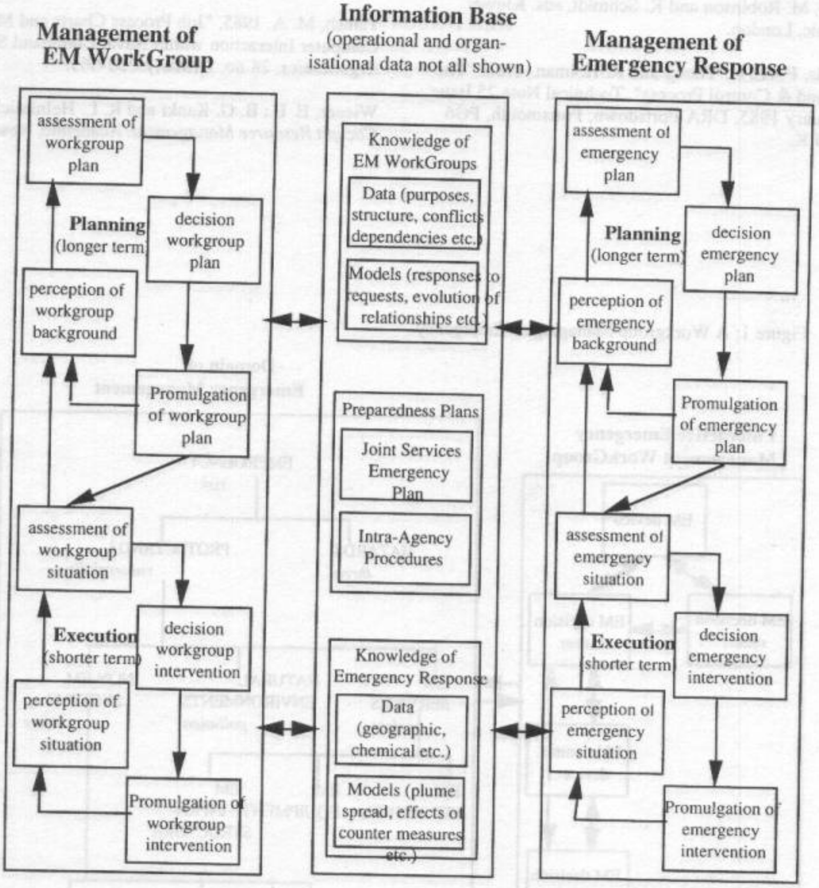


Figure 2: Structures that Support Co-ordinated Command Decision-Making



META - AND CONTINGENCY PLANNING IN COMMAND AND CONTROL CONTEXTS

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KEYWORDS: Computer Based Training, Command and Control, Contingency Planning, Simulation.

ABSTRACT

Maintaining Public Order at large events such as crowd demonstrations is a complex activity involving logistical and contingency planning and requiring shrewd management of strategies and tactics. Developing such skills can be assisted by computer based methods and a simulation system CACTUS was designed to achieve these objectives. It has several features of interest including a digitised map which agents navigate, multi-agent crowd models, time-line control to assist debriefing and graphical tools to guide the incident. The simulation permits multiple users to actively participate in the decision making, and if desired, the trainer can also shape and adjust the simulator, as it runs, in response to users decisions or to introduce other contingencies. The system is now being evaluated as part of training courses for senior police officers.

INTRODUCTION: THE TRAINING CONTEXT AND ITS REQUIREMENTS

Policing large scale incidents such as crowd demonstrations and marches is a considerable logistic exercise not only requiring contingency planning but sound strategic and tactical management. Errors of judgement may prove extremely expensive, and even endanger life. Furthermore, the resulting disorder can damage public confidence in the police and devalue the purposes of the demonstration.

Training such skills is difficult to organise and engineer. Managing demonstrations economically requires dispositions of appropriate police resources, an awareness of 'what-if' contingencies and a comprehensive strategic view of complex and dynamic interactions. Interpreting these scenarios gains much from previous experience. While tactical training can be arranged 'on the ground' organising authentic exercises to develop meta- and contingency planning skills can prove difficult and expensive. Simulation techniques can help to overcome some of these problems. Clearly the simulation should aim to be authenticate, and replicate, as near as practicable, the control room conditions and atmosphere of the real event. The decisions of the trainees and their consequences will need to be clearly observed and recorded, so they can be used in debriefing, and it would be valuable to have mechanisms for resetting the training simulation for a comparative re-running of alternative decision schemes. Also the trainer is likely to need opportunities to intervene either directly, or indirectly through management of the simulator. Since in the real situation different phases or aspects of the event are managed by different controllers, the system should accommodate multiple trainees able to communicate with each other.

Given these requirements computer based simulations, if they are appropriately designed, have much to offer, since they allow trainees to practice in a 'safe' environment but one which can generate some of the stress and the complexity of the authentic situation. To investigate the practicability and value of such methods, and in collaboration with the Metropolitan Police Office, a computer based system (CACTUS) has been developed to be used for training and, potentially, as an operational aid. The system covers both pre-incident planning with a testing of contingencies, and the management of simulated public order events with debriefing facilities. Its rationale and design are discussed in the following sections

SYSTEM COMPONENTS AND LEARNING ISSUES

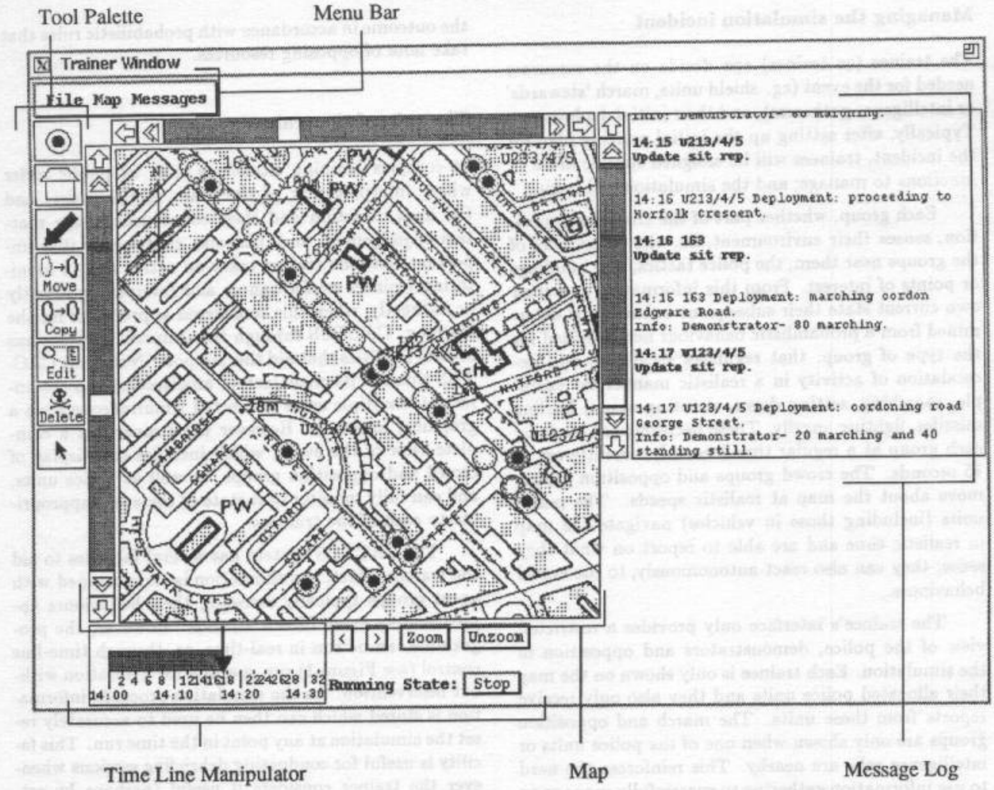
In designing the simulator a possible approach is to represent through video public order scenarios composed of a calendar of events, in which trainees' decisions and their consequences direct them upon particular training paths. This conception, though achieving some realism, is limited by the range of pre-stored materials which place constraints on the trainer's modes of use and the customisations of the materials to suit particular needs and objectives. The approach followed in CACTUS was to develop computer models of crowd behaviours that response to what they 'sense' in the environment and the policing tactics which are employed. This should have added flexibility and lead to a system where trainers themselves are able to compose the simulation exercises. The major components of the system are: (i) a representation of 'the world' in which the event takes place, based on a digital map that features buildings of interest to the crowd agents, and the route of the demonstration; (ii) crowd and opposition groups that can move about the map, and to which probabilistic behaviour networks are attached; (iii) police units which can navigate the map and be given particular functions and corresponding low-level autonomous behaviours that react to crowd and other group behaviours; (iv) a controlling 'referee' that arbitrates the consequences when groups (including the police) have conflicting behaviours and goals; (v) communication channels by which the trainee can instruct and secure feedback from the simulated police units, and links to trainees dealing with other aspects of the event; (vi) interfaces through which the simulation can be managed by the trainee, and the 'world' observed and particular interventions made by the trainers, and (vii) time-based record keeping facilities for dynamic debriefing.

In designing such simulations it is useful to consider how simulations support learning. Craik (1943) suggests that learners translate the 'external' objects and events with which they interact into internal (mental) models. Through reasoning, correspondences are noted between these mental conclusions and the time-based events in the simulated world. Norman (1983) in developing these ideas makes distinctions between: (i) the target system (eg the simulator) the learner is using, (ii) the conceptual model developed by the designer that underpins the target system, and (iii) the system image which the device (eg. the computer based simulation) conveyed to trainees will, in turn, influence their mental models, and the ways they understand the domain (Norman 1983; Staggers and Norcio 1993). These knowledge representations of the designer and trainee mediated by the simulator should be congruent for efficient learning, hence the trainer should be a key partner in the design with the simulator being able to be customised to particular views, and the conceptions of the trainees should noted through formative evaluation studies.

Sunderstrom (1993) makes the point that in control room management of complex processes what information is available (in the simulator) in relation to the trainee's tasks, how it is presented (through the interface) and when it is accessible all influence the development of mental models and understanding of trainees, and hence system design should be based on the information and knowledge users require and what presentation formats best support its use. The decision making task requires trainees to interpret the state of the world through time, to make interventions to achieve anticipated and desired effects, and to communicate relevant consequences to other users managing other aspects of the event. The interface has to facilitate these requirements, aiding interpretation by subsuming detail (of behaviours and events for example) under higher levels of granularity (shown perhaps by colour coding or by icons) and assisting interaction through direct manipulation that has shown to have considerable advantages (see for example Eberts and Bittianda (1993)). Where distinct functionality is given to different types of interaction (eg. map interpretation, instruction giving, or receiving messages) then the interface can have greater heterogeneity in its design (Avours, van Liederkerke, Lekkas, and Hall 1993). The system should also be capable of adjusting (for example through its task complexity or through its interface characteristics) to debriefing levels of trainee competence (Trumbly, Arnett, and Martin 1993). All these considerations were taken into account in the CACTUS designs, and its features and modes of use are now outlined.

SYSTEM IMPLEMENTATION AND MODES OF USE

CACTUS was implemented on a UNIX SUN-Sparc Workstation, but the client/server architecture allows Windows-based PCs to act as additional trainee stations. Two interfaces on the simulation have been developed, one for the trainer who will specify the simulation exercise and monitor and steer, as necessary, its application and debriefing with users, and a trainee's interface to allow map interpretation, and a log of the commands and reports.



```
14:15 U213/4/5
Update sit rep.

14:16 U213/4/5 Deployment: proceeding to
Norfolk Crescent.

14:16 163
Update sit rep.

14:16 163 Deployment: marching cordon
Edgware Road.
Info: Demonstrator- 80 marching.

14:17 U123/4/5
Update sit rep.

14:17 U123/4/5 Deployment: cordoning road
George Street.
Info: Demonstrator- 20 marching and 40
standing still.
```

Figure 1: Annotated Trainer Interface

Pre-incident planning

In CACTUS the trainer is able to specify the route on the digitised map by indicating the points through which the demonstration march is expected to pass. The trainer will also specify the number and type of crowd elements making up the march (eg. peaceful or excited groups). Using the trainers' tool palette (see Figure 1), buildings or points of interest to the marchers or opposition groups or police, can be marked (eg. politically sensitive buildings or scaffolding that might prove a source of weapons, or shops that might attract looting). The palette also enables groups to be created on the map, which is used to specify the initial location of opposition groups.

Given this information the system is able to help by working out the expected time of completion of the march along the route, and the actual number of police engaged. This permits a rough estimate of the 'resource cost' of that particular policing strategy to be estimated. Thus CACTUS can become an aid to the pre-event planning and requirement specifications for actual events as well as serving as a training aid. For example the trainer (or the trainees) are able to set out their decisions and justify them, as necessary, and also try out "What-if contingencies" eg. if particular opposition groups are strengthened or the march is hijacked or a car accident occurs on the route. The simulator can be run against these particular occurrences and their consequences for the policing strategy noted.

Managing the simulation incident

The trainee (or trainer) can decide on the resources needed for the event (eg. shield units, march 'stewards' or intelligence gatherers), and their initial deployment. Typically, after setting up the initial policing plan for the incident, trainees will be assigned specific areas or functions to manage; and the simulation will begin.

Each group, whether part of the crowd or opposition, senses their environment, i.e. the behaviours of the groups near them, the police tactics, and buildings or points of interest. From this information and their own current state their subsequent behaviour is determined from a probabilistic behaviour net, specified for the type of group, that regulates escalation and de-escalation of activity in a realistic manner for example, marching, setting down, shouting abuse, hurling missiles, fighting angrily. These decisions are made by each group at a regular time interval, currently set at 15 seconds. The crowd groups and opposition groups move about the map at realistic speeds. The police units (including those in vehicles) navigate the map in realistic time and are able to report on what they sense; they can also react autonomously, to the crowd behaviours.

The trainee's interface only provides a restricted view of the police, demonstrators and opposition in the simulation. Each trainee is only shown on the map their allocated police units and they also only receive reports from these units. The march and opposition groups are only shown when one of the police units or intelligence cells are nearby. This reinforces the need to use information gathering to successfully manage an incident. Restricting the view to only their 'own' units is intended to promote collaboration between trainees so that they don't work in isolation.

Trainees have to monitor and interpret the event, receiving or requesting information of the crowd state from police units and intelligence cells. This information is recorded on a Message Log (see Figure 1) and in response the trainee can make strategic and tactical decision and send the necessary instructions to the police units (eg. form shield cordon). The chosen units take up these actions in real time. The communication from trainee to police units can be achieved through an on-screen message panel, or if preferred, by sending the instruction via radio-telephone to the trainer who then acts on the user's behalf. In this way the simulation exercise proceeds with trainees also relaying appropriate messages to those users managing other stages of the demonstration march. When there are conflicting goals between crowd groups, hostile elements, or police units, CACTUS employs a computer referee to decide the outcome in accordance with probabilistic rules that take note of opposing resources.

The role of the trainer

In complex training situations such as public order where interpretation of the state of the event, and the lines of action and their consequences, are matters of judgement and, perhaps, controversy it is important that the trainer takes an active role in monitoring trainees performances and intervening directly or indirectly, when this considered appropriate for the learning. CACTUS through the trainers' interface has several facilities that aid this support. Note that CACTUS through its client/server architecture can accommodate multiple users connected simultaneously via a graphical interface. However the trainer has a complete view of the event, which includes the display of crowd and opposition groups, as well as police units, and can fully monitor that state of the event appropriate to each of the trainees.

The CACTUS System has several facilities to aid the trainer. First, the simulation is time-stepped with agent groups typically assessing their behaviours approximately every fifteen seconds. However, the programme can be run in real-time, or, through time-line control (see Figure 1) run speedily for a duration without intervention. As the simulation proceeds information is stored which can then be used to accurately reset the simulation at any point in the time run. This facility is useful for conducting debriefing sessions whenever the trainer considers it useful (perhaps by setting the simulation at any earlier time point to discuss how trouble arose, and for the simulation to be re-run from that time-point with a different action plan, or to forward-run the simulation to underline particular weaknesses in a policing or information gathering strategy). The sequence of state information of the simulation can be stored in a file and then recovered to continue the exercise at a later date or to store as an example in a case-study archive.

Second, to help the trainer in interpreting the complexities of the event, each type of agent group (shown on the display screen as a circle at their location on the map) is colour coded to indicate if it is a police, crowd or opposition element. Further each group icon is surrounded by a halo which, as the behaviour becomes more aggressive, is coloured a deeper shade of red. Hence the trainer can quickly identify developing pockets of discontent.

Third, the trainer can place icons from the tool palette on the map and attach short comments, if necessary, to describe a particular type of hazard or area of interest. This can be used as an attention note for the debriefing, and the trainer can also place instructional comments as marginal notes in his message log. It can also be used to introduce events not directly supported by the simulation, for example to indicate a fire that the march would have to be routed round.

Fourth, the state of the simulation can be altered by the trainer in ways which are not directly perceived by the trainee. For example, opposition groups can be moved or other groups added to the scene. These groups will, no doubt, be reported by police units to the trainees log in due course the trainer himself can add reports, for example as a bystander or as a police unit and by these methods latent weaknesses in the policing strategy can be exposed or the trainees' attention drawn to them.

Adapting to the trainee

These facilities allow trainers to manage the pre-event planning and contingency testing, the management of the event and the debriefing, in a variety of ways which suit particular objectives and the experience of the trainees. Indeed a wide variety of types and complexities of events and incidents can be presented in such training exercises. The simulation can also be organised with small groups, rather than individuals, managing the decision making at each workstation.

Additionally trainees can have access to other supporting material. Hypermedia case studies of previous incidents are being stored in an archive, and linked to this material is information to configure the simulation to match significant events during these incidents. Running the simulation within these prescribed contexts should also provide useful insights. Perhaps, more importantly, these case studies which illustrate previous experience in the disposition of resources and tactics can be used as operational briefing aids for events that take place regularly and follow the same or similar map routes.

Evaluation and Extension

CACTUS has undergone its initial trials and now is a training component in courses for senior police officers. Evaluation data is being collected, and the questions of interest include the ways trainers decide to use the simulator, and the facilities they employ in pre-incident planning, event management and debriefing. Similarly there is interest not only in the performances of trainees, but in their views of using the system and those facilities which they consider improve their planning and decision-making capabilities.

Current consideration is being given to the ways similar design principles could be applied to the management training of other emergency situations where many types of interacting resources require logistic and contingency planning, and where agent behavioural networks could be applied. If CACTUS proves successful then similar facilities and methods can be brought into other simulations and hence provide greater flexibility to instruction, and more adaptive trainee and trainer support.

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TIEMEC '95

Tactical Training for Emergency Management

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EXPERIENCES FROM TACTICAL TRAINING OF OPERATION CONTROL CENTRE PERSONNEL IN EMERGENCY SITUATIONS.

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ABSTRACT

This paper presents the experiences from two tactical training courses aimed at emergency situations for staff in the operation control centre for city trains. The design of each course is presented, followed by a discussion in which the consequences of the two designs are compared. The comparison gives several indications as to the need for performing a task analysis as part of the design process, and for the need to include in the design a training method aimed at experts/professionals.

INTRODUCTION

In this paper experiences from two tactical training courses conducted in the Danish Railways are presented. The courses were directed at personnel in the operation control centre for city trains. In both courses the general purpose was to improve the operators' skills for handling emergency situations. Identical design principles were used to develop the courses, but the actual designs differed in several ways. It is the purpose of this paper to outline and discuss the consequences of these differences. The paper describes the results of a pilot-study carried out in relation to the MUSTER-project[1]. The intention was to examine what kind of experiences the Danish Railways had so far with tactical training for in order to the MUSTER-system to benefit from this knowledge.

Method

The two courses were compared on six different issues central in a design process: 1. Training purpose. 2. Trainees. 3. Physical design. 4. Development of scenarios. 5. Choice of assistants, and 6. Training and evaluation method. The comparison is based on various inputs. This includes the course books from the training sessions (DSB, 1992; DSB, 1993) and the evaluation schemes filled in by the participants. Three interviews with the designers primarily responsible for the training programs have been conducted. The interviews were carried out as qualitative research interview (Kvale, 1983) and lasted in average two and a half hour. The primary purpose with the interviews was to identify the rationale behind the design process, which was not clarified in the course books. All designers had participated in at least one course as assistant. Accordingly, the interviews also focused on how this experience had influenced their reflections regarding the effectiveness of their design.

General remarks about the courses

The simulator used comprised two rooms. In one room the control centre was simulated. In the other room facilities needed to control the games were installed. Three types of participants were involved in the games: Trainees, instructors and assistants. The trainees were all experienced operators. Each trainee participated in two games. A chief instructor lead the games, supported by various assistants. Some assistants played the role of different people whom the trainees might wish to contact during a game. Others sup-

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[1] CEC Environment Program, proj. PL 910675.

ported the instructor in different ways (this included the designers). Each course lasted for two days.

The training design of the first course

Course number one, was the first tactical training course ever held in the Danish Railways. It was seen by the designers as a pilot experiment. The *purpose* of the course was to improve: 1. Ways of collaboration. 2. Communication both inside the control centre and between the control centre and external partners, e.g., the police, and 3. Systems and procedures.

The training aimed at all team members in the operation control centre, and thus all team members were *trainees*.

During the design process the designers assumed that the most important issue was to make the sessions as realistic as possible -- given the practical and economical constraints. Accordingly the *physical construction* of the simulated control centre was set up to mimic the actual control centre. It turned out to be difficult to simulate the large control panel used by the operators to monitor the movements of the trains.

To make sure that the *scenarios* would seem realistic to the trainees the designers followed at least two principles: 1. Not to include "too many" incidents in each scenario, and 2. To situate the incidents on specific locations on the tracks imbedding the constraints of the chosen spot in the scenario. The designers feared that the trainees would see the games as unrealistic if the incidents included exceeded a certain number (the specific number was not specified). They also feared that the trainees would not accept the scenarios as realistic if they could or should act differently towards an incident in the game compared to what their tasks would be in a real situation. The designers found that all minor emergencies could be used as incidents in the scenarios, because they all would create a need for co-operation. The scenarios were designed to cover only the first twenty minutes of a game. The designers felt that after twenty minutes (with maybe nine different incidents) the training situation which the trainees met would be sufficiently complex to keep the trainees busy for a long period of time. The participating *assistants* were to a large extent people whom in reality held the same position as the one they played during the games.

The *training method* used was straightforward. The games began with introducing the incidents specified in the scenario and went on until the normal traffic flow was reestablished. During the games the instructor stayed in the background. If the trainees made any errors, he noticed it, but he seldom intervened. This implied that the trainees would met the exact consequences of their actions as the game developed. After each game an evaluation session was held. Here the instructor commented on any faults he had noticed during the game. The trainees were encouraged to state their own opinions as to what had happened, and thus the evaluation took form of a discussion between operators and instructor.

RESULTS

The effect of the course was judged to be very positive by all involved. The trainees felt that the sessions offered an excellent opportunity both for practising emergency procedures and for discussing how a concrete emergency had been handled. To some surprise for the designers the assistants also benefitted from the training. The assistants stated that their participation had given them new insight concerning the situation in the control centre during an emergency. This insight implied that they would react differently towards the control centre personnel in cases of future emergencies compared to what they did previously. E.g., reduce the amount of "unnecessary" calls to the control centre.

The training design of the second course

In the second course the focus of the sessions had changed from the team as such to the role of the duty officer. The designers felt that the authority of the duty officer in situations of emergency should be established more explicitly. The *purpose* of the session was specified to be: 1. To focus on the decision making process, and 2. To give the duty officer an understanding of the emergency procedures. Though the focus was on the duty officer all team members were conceived of as *trainees*.

The sessions were developed following the same principles as in the first course. The construction of the simulated control centre was changed a little to make it more realistic due to feedback from the trainees in the first course.

The *training method* used differed significantly from the one applied in the first course. In the second course the instructor played a much more active role during the games. When the duty officer made a mistake or sat up a strategy which the instructor did not find adequate, he would interrupt the game. Often this would lead to a debate including only the duty officer and the instructor. In these situations other participants could do nothing but wait. Occasionally the instructor chose to repeat a sequence of the scenario (to set the time back) to give the duty officer a change for correcting his actions. This implied, that the other participants also had to repeat the sequence. The games in the second course were ended shortly after the consequences of the duty officers strategy began to appear. Thus, the duty officer never experienced the full consequences of the chosen strategy. As in the first course all participants were present during the evaluation sessions, but this time the instructor controlled the sessions more rigorously. The evaluation focused on the performance of the duty officer. The instructor stated where the duty officer had made inadequate decisions and how he could do better. Neither the duty officer nor other team members had much opportunity for discussing the situations that had occurred during the game.

RESULTS

The result of the second course was judged rather negatively by the participants. One of the team members stated that he felt the duty officer had been publicly "slaughtered". The team members complained about the waiting time during the games and were annoyed by the frequent interruption which they did not always understand the reason for. Furthermore some team members felt confused as to their role in the game. Also the assistants complained about the waiting time and found the games somewhat boring. Only few of them commented on gaining new insight into the work of the control centre personnel.

DISCUSSION

The courses presented above were designed according to the same general principles. They were alike except for three of the issues examined: purpose of the course, trainees, and training and evaluation method.

In literature on training the need to perform a task analysis as foundation for a design process is stressed (e.g., Patrick, 1992; Briggs & Wager, 1981). Through the analysis the exact purpose of the session should be specified and criteria for evaluating performance established.

In neither of the courses presented here a task analysis was carried out as part of the design process. The designers, who were all familiar with the domain, found it easy to identify *the purpose* of the sessions and felt no need for a detailed analysis. After specifying the training purpose in somewhat broad terms (as described above), the designers turned their attention to the creation of the "content" of the games -- the scenarios. As noted previously the designers wished to devise a realistic training environment. The rationale was that if a realistic environment was created the trainees would be able to act as if the situation was real. It was assumed, that if the trainees would act realistically they would surely benefit from the sessions. It wasn't specified how the skills of the trainees were expected to improve as a result of the sessions. The reason for this was, that the designers felt, that the actions of the trainees could be evaluated in the same way as if the emergency had been real - and that such an evaluation would suffice.

These design principles turned out to have different consequences in the two courses.

Focusing the *purpose* of the sessions on the duty officer (as in the second course) had implications for the rest of the team members which were not foreseen by the designers. Even though the tactical trainer was seen as a mean suited for training of teams, the duty officer was in fact the only *trainee* in this course. Only his actions were in constant focus of the instructor. The actions of the other team members were only debated if they negatively influenced the task performance of the duty officer. Thus, the rest of the team were as such assistants. If the consequences of the training purpose had been foreseen, the roles of the rest of the team could have been made clear to them in advance. The team members dissatisfaction with the waiting time, confusion as to their roles etc. might then have been overcomed.

The *training and evaluation method* used in the two courses differed on several points. The ending of a game shortly after the consequences of the chosen strategy appeared (in the second course), had an overall negative effect on the motivation of the trainees. The reason for this could be that such a strategy denies the team members the opportunity to experience the success of reestablishing a normal traffic flow.

The instructors' interruptions and redirections of a game in situations were he found the strategy developed by the duty officer was inadequate (in the second course), also had a potential demotivating effect on the trainee. This risk is obvious in situations were a duty officer feels that his own strategy would have succeed if only it had been given a change.

The lack of explicit criteria for evaluation was not immediately obvious in the first course. Actually the trainees did most of the evaluation themselves. The trainees felt no need for criteria, because they could discuss the situations in the game, as they would or at least could have done if the situation had been real. In the second course the lack of explicit criteria was more noticeable. From time to time the instructor found it difficult to support his statements, e.g., in situations where the style of communication or the potential use of a given strategy were addressed. In these situations he had to resort to say that such and such was his impression. The trainees tended to reject such an argumentation. They often felt more able to speculate about the cause of the problems, than the instructor. As the trainees only to a minor extent were allowed to state their own opinions, they generally experienced the evaluation sessions to be quite frustrating.

CONCLUSION

The experiences from the two tactical training courses underline the need to perform a task analysis as an integrated part of the design process. The analysis would secure 1. That tasks which cause problems to the team members are explicitly addressed, and 2. That a set of criteria for evaluating performance is established. The establishing of criteria is a prerequisite if the instructor is to give effective feedback to the trainees. The identification of criteria is also necessary to demonstrate a training effect. The criteria will enable the designers to point at specific skills which have been improved in the sessions. The two courses described here were experienced very differently by the trainees. Still, because criteria for the evaluation performance wasn't explicitly stated, it is impossible to say if the purpose in either course was accomplished.

Tactical training as used in the Danish Railways must be seen primarily as a tool for training of teams. Accordingly, the Danish Railways will consider to use another training media if the need for training a single team member should arise again (as in the second course). This would be a less costly solution than to involve the hole team in a training session.

The experiences from the two courses also point towards a need for establishing a training and evaluation method aimed at expert trainees. The experienced team member can be expected to act according to a reasonably well thought out plan - even though this may not be immediately evident for the instructor. Accordingly the instructor should be careful not to interrupt a game unwarranted. It seems preferable in most cases simply to allow the expert trainee to experience the full consequences of the strategy he has developed. If it turns out that the strategy isn't optimal after all, the instructor can point out the reasons for this during the evaluation session. In such a situations the expert trainee is likely to listen more carefully to corrections from the instructor, than in situations were he feels, that his own strategy would have succeed after all.

It seems preferable to let expert trainees participate actively during the evaluation sessions. The expert trainees are sufficiently experienced to discuss an instructors' observations and corrections in a qualified way. Of cause they won't be experts in evaluation of performance or, like the instructor, be able to compare their own actions to that of other trainees. Still, a discussion in the team, would make all team members reflect about their own tasks and needs in an emergency situation. If the evaluation is carried out primarily by an instructor this type of reflections might not occur.

The Danish Railways' experiences with tactical training have so far been very instructive, as the two courses have given many indications regarding the consequences of different design options. The Danish Railway's see tactical training as a very powerful tool for training of teams, because it allows a team to practice together on a common goal. As such tactical training is seen as a potential tool for many training purposes in the organization.

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TACTICAL TRAINING AT THE DANISH NATIONAL FIRE COLLEGE

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ABSTRACT

At the Danish National College the tactical training of fire officers takes place in a model town, scale 1:100, which is used both directly and in connection with an ITV-system. The model town has been built up like a typical Danish community of medium size with an old city center, industrial and residential areas and rural areas with small towns and villages.

The training programme involves 3 steps. The courses start with a series of tactical situations which the students discuss in groups of 4-6 persons. The next step is tactical exercises, and now the time factor is taken into consideration. The third step is "Combined Operations". These exercises are carried out exactly the same way as full-scale exercises.

The use of the model town presents some problems, since the whole area can be viewed at one time. To avoid this disadvantage a special technique has been developed. A very small camera "drives" through the streets of the model town. The lens is placed at a height corresponding to a man's eye-level. The camera is connected to a TV monitor and the screen shows the same picture as a man walking in the street would observe.

INTRODUCTION

In Denmark the *technical* training of firemen takes place in a training center, where firemen with heavy breathing apparatus fight fires in buildings of different types, in flammable liquids, in motor cars, etc. While this type of training must take place in full-scale fires, a similar training of fire officers and sub-officers in firefighting *tactics* is not possible. For this training some kind of *simulation* must be used. At the Danish National Fire College in Virum, 20 km to the north of Copenhagen, the tactical training takes place in a model town, scale 1:100, which is used both directly and in connection with an ITV-system.

THE MODEL TOWN

The model town is called *Skoleborg*. The community of Skoleborg has been built up like a typical Danish town of medium size. The population is 50.000 and the community consists of an old city center, industrial and residential areas and rural areas with small towns and villages. Of special interest for firemen are the densely built-up old town, the docks, the oil harbour, the chemical plants and the airport.

The fire brigade of Skoleborg has been built up according to the Danish standards of fire safety. The fire station and all the appliances also exist in scale 1:100.

A map of Skoleborg shows all the important details, including the positions of hydrants and other water supplies.

A description of Skoleborg Fire Brigade gives all details about the appliances and the equipment. At the beginning of each course the students must familiarize themselves with Skoleborg and its fire brigade.

SYSTEM OF COMMAND

According to the Danish standards of fire safety, the first attendance in bigger towns is a water tender with a crew of one sub-officer and five firemen and a turntable ladder with a crew of two firemen under the command of a fire officer who uses his own car.

When the fire officer arrives at the scene he sizes up the situation, and as soon as the appliances arrive he gives orders to the sub-officer. The sub-officer's job is to give orders to the firemen and to check that the work at the fire scene is carried out in accordance with the fire officer's order. At larger fires further appliances will arrive, all of them manned according to the above mentioned rules. The fire officer is in command of all forces at the scene.

USE OF MODEL TOWN

The training programme involves tactical courses at two different levels, sub-officers' course and fire officers' course, and the tactical training takes place in the model town. After an introduction in the use of the town, the courses start with a series of tactical situations which the students discuss in groups of 4-6 persons. The next step is tactical exercises, and now the time factor is taken into consideration. A situation is set up on the model and after a short briefing the student, acting as fire officer, is given 60 seconds to plan his attack. Then another student, playing the role of a sub-officer, arrives and the fire officer will give his orders. After a few seconds the sub-officer must give his order to the firemen.

The third step is the so-called "Combined Operations". These exercises are carried out exactly the same way as full-scale exercises. The students occupy the fire station, the police station, the ambulance station etc., each of them playing a particular role such as commanding officer, sub-officer of the first attendance, police officer or ambulance leader. When the control room receives an alarm the units are dispatched with correct time intervals. At the scene of accident fires are extinguised, victims are rescued etc. exactly like in a real accident.

The model town is also used for big exercises for experiensed personnel with participation of fire officers, police officers, ambulance service, medical teams etc.

ITV-SYSTEM

Some situations spread over a large area and here the use of the model town presents some problems, since the whole area can be viewed at one time, which makes it much easier to plan an attack. In a real situation a fire officer, walking in the street, could see only a small part of the damage. To avoid this disadvantage a special technique has been developed. A very small TV camera "drives" through the streets of the model town. The lens is placed at a height corresponding to a man's eye level. The camera is connected to a TV monitor and the screen shows the same picture as a man walking in the streets would observe.

When this equipment is used, students occupy a room where they cannot see the model town. They base their plan of attack solely on the TV pictures. The TV system can be used in two ways, by direct transmission or by recording. With direct transmission the camera operator moves the camera following the directions of the fire officer, i.e. the officer decides what he wishes to see. With a recording, the complete situation is recorded on videotape in advance and the officer can play the tape forwards and backwards just as he likes. In both cases the student sees the situation in the same way as he would at a real fire.

The ITV system has been used at the National Fire College for several years with a very good result.

THE USE OF SCENARIOS AND GAMING IN CRISIS MANAGEMENT PLANNING AND TRAINING

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ABSTRACT

This paper provides a brief introduction to scenarios and gaming. It clarifies the definitions of each, discusses their possible uses and purposes, and presents some principles of good practice. It then describes how scenarios and gaming can be used together with a computerized crisis management decision support system to provide useful tools for crisis management planning and training.

INTRODUCTION

Crises are rare events. Each crisis is different from other crises. Among the variables that define a crisis are its type (e.g., flood, explosion, war, airplane crash), location, affected population, and relevant support organizations. These variables are practically impossible to predict in advance. Also, the crisis and the resources available to deal with it are continuously changing over time. The problem that organizations responsible for national management of major disaster response activities face is how to deal with these "state of the world" uncertainties in preparing to handle crises. Quade (1989) defines state of the world uncertainties as those that are beyond the practical ability of analysts to predict and cannot be reduced to risks. Two ways of dealing with these uncertainties, which I describe in this paper, are the use of scenarios and gaming. In fact, in my suggested approach for dealing with the above problem, these two ways are interdependent. A scenario becomes the starting point for the game; and the structure and purposes of the game shape the boundaries and content of the scenario. Both of these approaches have been used for similar purposes over the past thirty years. But I propose taking advantage of advances in information systems and telecommunications to make these approaches more useful and effective than they have been in the past.

SCENARIOS

Some Definitions

Scenarios can play an important role in crisis management and contingency planning. The use of the term *scenario* as an analytical tool dates from the early 1960s, when researchers at the RAND Corporation defined states of the world within which alternative weapons systems or military strategies would have to perform. Since then their use has grown rapidly, and the meanings and uses of scenarios have become increasingly varied. As a consequence, misunderstandings and communication problems about scenarios can arise easily. I therefore, wish to begin by defining what I mean by a scenario in the context of crisis management.

For the purposes of this paper, I propose the following definition of a crisis management scenario, which is based on a more general definition suggested by Quade (1989): *A description of the conditions under which the crisis management system or crisis management policy to be designed, tested, or evaluated is assumed to perform.* The terms context, setting, situation, or environment are often used loosely as equivalents to the term scenario, but I make some distinctions among them.

In particular, I propose to split a crisis management scenario into two parts--the context and the crisis. The *context* may be described as the overall background or environment within which the specific crisis is to be considered. It is the state of the affected area at the time of the crisis. For example, it would define, for a given point in time, the demographics, the geography, the organizational relationships, the availability of data, the telecommunications situation, etc. The context is an environmental framework into which many different crises might be embedded for study.

The *crisis*, on the other hand, is a script for the specific crisis. It includes the chain of (hypothetical) events that lead up to the crisis. If gaming is to be used to examine possible responses (as I propose here), it would also include the exogenous events during the period of the game (the chain of events outside the control of players in the system). For example, the crisis would describe the weather, political events, etc. both before and during the specific crisis. It is the sequence of events to which the crisis management system must respond. For a flood, it would specify the times and places where specific dikes were breached, services were disrupted, persons were swept away, etc.

The context plus the crisis prior to the start of the game would provide the players with the necessary background information about the situation to enable them to specify the initial conditions for their response activities. Also, of course, the purpose of the game would provide several parameters that are vital to the scenario, such as the setting, potential list of actors, and many of the "rules of the game".

The scenario is defined by the values of a set of variables. Some scenario variables are controllable by government agencies, organizations, and individuals (e.g., the numbers and locations of rescue equipment), and some are uncontrollable (e.g., the weather). Some uncontrollable variables may be able to be predicted probabilistically (e.g., weather), and some may be unknowable (e.g., the political situation at the time of the crisis).

Why Use Scenarios?

A scenario describes a hypothetical, but plausible, situation that may be used for a variety of purposes. DeWeerd (1967) lists four purposes of scenarios that are relevant for crisis management:

- To supply the starting point and exogenous events for a game.
- To supply a consistent and plausible situation as a background for the discussion of a proposed [crisis management] system or [crisis management] policies.
- As an environment in which to examine the functioning of various [response] strategies.
- As a background for contingency planning.

Scenarios are primarily communication devices. Although they do not reduce the uncertainties inherent in describing a future state of the world, they make situations more concrete, so users can treat a proposed response strategy or crisis management system within a self-consistent and plausible set of circumstances. DeWeerd quotes Herman Kahn as saying, scenarios are meant to "stretch the mind and force a planner to envisage the future in concrete terms." And Quade (1985) points out that well-formulated scenarios have proved useful in broadening the number of contingencies taken seriously in military and industrial planning "by forcibly illustrating the advantages or pitfalls of various proposals or of a new capability."

A scenario specifies a possible, but not necessarily probable, context and series of events. Its usefulness for crisis management planning or decisionmaking does not depend on its accuracy or the probability of its occurrence. (This is somewhat different from its usefulness for policy analysis purposes, where the probability of the situation occurring can be an important factor.) In fact, when using scenarios it is crucial to keep in mind that they are not predictions. The treatment of a scenario as a prediction is one of the most common mistakes made by both their creators and their users, and time should not be spent arguing about the relative probabilities of occurrence of alternative scenarios. The scenario creator should not be claiming that the events he is describing are likely, but that they are not completely impossible, and that they are plausible enough to be taken seriously by contingency planners.

There is no general theory that allows us to assess scenario adequacy or quality. There are, however, a number of criteria that are often mentioned in the literature as being important. Schwarz (1988) gives a brief summary of them. The most important of these in the crisis management context are consistency, plausibility, credibility, and relevance.

Consistency simply means that the assumptions made are not self-contradictory. It is not easy to create a future that is internally and externally consistent (novelists and filmmakers also find it difficult). But, inconsistency in a scenario will raise questions about its validity and usefulness. One of the early tests of the validity of a scenario was whether a sequence of events could be constructed that would lead from the present state of the world to the scenario's future state. According to Helmer (1966), although the purpose of a scenario is not to predict the future, "it nevertheless sets out to demonstrate the possibility of a certain future state of affairs by exhibiting a reasonable chain of events that might lead to it." As DeWeerd (1967) states, "In a good scenario there should be no great unexplained leaps, no uninvented weapons, no reversal of the laws of gravity, and no inner contradictions."

The term *plausible* is used to distinguish a scenario from a prediction. It is a statement that the posited chain of events *might* happen (not *will* happen). Although the specific events may be highly unlikely to occur at the times indicated or the levels assumed, if a scenario is plausible, then a similar sequence of events might very well occur. Plausibility is a great virtue in a scenario, but, as Kahn and Wiener (1967) point out, the scenario writer should not limit himself to the most plausible possibilities, since "history is likely to write scenarios that most observers would find implausible not only prospectively but sometimes, even, in retrospect." For example, DeWeerd (1973) notes that "a scenario of the Watergate bugging attempt, written before 1972, would have been held up to scorn by 'reasonable' men, as would a scenario written before the Pearl Harbor attack, the Berlin Blockade, the Berlin Wall, or the Cuban Missile crisis."

Credibility is closely related to plausibility. For a scenario to be credible, each change from the present circumstances or those existing at a previous step in the chain should be explained. It is all right to predict that some unforeseen events will occur. However, in mentioning a particular event, it is important to understand why it occurs. If it does occur by "accident", its role in the scenario should not be too important. Otherwise, the scenario loses its credibility and some potential users might refuse to use it. In some cases, the purpose of the scenario should take precedence over credibility (see the discussion of 'relevance' below). But such departures from reality should be explicitly noted.

To be useful, the form, role, and content of a scenario must have *relevance* to the problem at hand. For contingency planning for crises, for example, it might be worthwhile to posit what is usually regarded as irrational behavior by a perpetrator or a development that may be extremely unlikely but would have important, possibly dangerous, consequences.

The Design of Scenarios

Since scenarios may have many uses, the quality and usefulness of a scenario can only be judged according to the use to which the scenario will be put. That is, the form and content of a scenario has to be determined by the specific task at hand. If being designed as input to a game, the purpose and structure of the game will dictate many of the elements of the scenario. Also, the boundaries of the games (what is endogenous and what is exogenous) will dictate the boundaries for the scenario. This information will provide the setting, the geography and demography, the list of players, the "rules of the game,", and other parameters that are vital to the scenario.

Although it is impossible to generalize about how to set the boundaries of a scenario or what form they should take, de Leon (1975) suggests four decisions that are important in the design of any gaming scenario:

- **Time setting.** For crisis management games, the time should be the present. What we want to determine is how the current crisis response system is working, and what can be done to improve it.
- **Environmental setting.** The environment should be as little changed from the current world as possible. Aspects to be covered include demographic distributions, geographic descriptions, and as much additional information that the players should know in order to make their decisions.
- **Level of detail.** The conditions for the geographical area where the crisis occurs should be carefully delineated and described. However, the amount of detail should be limited to only what is necessary. Players can only absorb and manipulate a limited amount of information; to overload them with trivia would be self-defeating for the purposes of the game.
- **Knowledge, experience, and sophistication of players.** The fewer skills, background, and knowledge the players bring to the game, the more thorough the scenario must be. In the games I am proposing, the players should be playing roles they would be playing in the real world, so the scenario need not fill in too many details.

GAMING

Some Definitions

Abt (1970) defines a game as "an activity among two or more independent decision-makers seeking to achieve their objectives in some limiting context." War games date at least as far back as 500 B.C., when the oriental general Sun Tzu is reported to have said "the general who wins a battle makes many calculations in his temple ere the battle is fought" (Weiner 1964, p.217). Man-machine simulations and war games (utilizing computers to play one of the sides) began to be used in the early 1960s at the RAND Corporation to study real-world political-military crises. (For discussions of the techniques they used and situations they considered, see Geisler and Ginsberg (1965) and Shubik and Brewer (1972).) Since then, the use of games for a variety of teaching, training, and research purposes has mushroomed. They have helped in developing military strategies, in pretesting government policies before implementation, and in helping to understand operational complexities in many contexts. Schwabe (1994) provides a brief introduction to gaming as an analytical tool. Much of the information in this section is drawn from his paper.

Most games have two or more players, each representing a decisionmaking entity. Each player is assigned a specific role--e.g., leader of a country, president of a firm, chief at the scene of a fire. Play of a game is usually divided into moves, each of which begins with the presentation of information that players are asked to accept as true and to use as a basis for their deliberations and decisions. This information is called the *scenario* for the game. In the terminology used above, the game would be preceded with a presentation of the context and the crisis up to the beginning of the game. The playing of the game usually involves another set of persons who administer the game. They are commonly called controllers or referees, and usually include those who designed the game and those who will analyze its results. Games have usually been played with all participants at one site; however, distributed games can be played with remotely located players communicating via computer networks, video conferencing, or other means. (For example, on 4-7 November 1994, a distributed interactive simulation (DIS) exercise was conducted that involved the participation of sites throughout Europe and North America.)

Why Use Gaming?

Gaming can be used for many purposes. Shubik (1971) divides these into six categories. Crisis management games can be designed to achieve four of these:

- **Teaching**. One of the major uses of gaming has been as a motivational aid to learning. Business games are used extensively in business schools for this purpose. Gaming has been found to attract the players' attention and involve them deeply. It is an extremely useful way to learn and organize facts. And, because of a game's logical consistency and completeness, it is a useful device for encouraging students to think in terms of models and abstractions. It is also a useful device for teaching about interpersonal relations, such as the need for cooperation, communication, negotiation, and compromise.
- **Training**. Games can be used to improve the performance of a group of persons in an organization in carrying out their normal jobs ("off line", so that mistakes do not affect actual outcomes). More important for crisis management, however, is that games can be used as "dress rehearsals", just as in the theater. In this case, they are aimed at preparing for coordination of the players who may have to cooperate in team action on a temporary basis.
- **Operations**. Operational games are used by military, governmental, and corporate organizations for contingency planning, strategy exploration, and system testing. In this type of use, the game can reveal errors or omissions in a strategy, explore assumptions and uncover those that are implicit, examine the feasibility of an operational concept, identify areas in which required information is lacking, and suggest areas needing further attention.
- **Experimentation**. Human beings are more difficult to experiment with than rats or guinea pigs. In experimental gaming, human decisionmaking behavior is studied by observing the performance of individuals in an experimental setting. Crisis games, for example, might be used to study decisionmaking under stressful, overloaded, conditions.

Schelling (in (Levine, Schelling, and Jones 1991)) is more specific about what he thinks crisis games can accomplish. Because of the relevance of his insights, I quote him at length:

> [G]ames are . . . awfully good at . . . demanding careful sequential analysis of plans, decisions, events, and intelligence. Very few plans or situations seem to be subjected to a process of 'walking through,' of dress rehearsal. This is particularly true of plans and contingencies that are political-military, i.e., that involve . . .communications, intelligence activities and interpretation, and the coordination of activities over time as well as among agencies. Crisis games typically subject the players to a continuous process over time in which they are both making decisions and living with prior decisions, in only partial control of their environment, committing themselves to actions that have lead times, reaching decisions on the basis of intelligence that is only partially available when they cannot wait for more. People sensitive to a variety of responsibilities collaborate, applying the criteria that are relevant to their own interests, making estimates that reflect their own kinds of knowledge, and putting themselves in a mood to worry about probabilities rather than just a list of possibilities. They really live through a simulated crisis and not only learn things about their plans and their predictions but learn something about the nature of crisis.

THE USE OF SCENARIOS AND GAMING AS METHODOLOGICAL TOOLS TO IMPROVE CRISIS MANAGEMENT

Advances in computers, networking, and telecommunications open up new possibilities for using gaming as a methodological tool for improving crisis management. It is becoming easier to develop models to support games, to have players at distributed workstations interacting with each other, to have automated controllers supply exogenous events to the players, to enable players to query online data files during the game, and to prepare presentation graphics for use during the game and for post-game debriefings. Videotapes can be used to present scenario updates to players in "newscast" format and to present pre-taped briefings by experts to players. Organizations with responsibility for crisis management (e.g., the Netherlands Ministry of the Interior) are in the process of considering how such new technologies can be used in constructing a crisis management system (CMS) to coordinate response to a crisis, provide decision support during a crisis, and support activities prior to the crisis and after the crisis. (Such a CMS might have elements like those shown in Fig. 1.) If designed correctly, that same CMS could be easily used in a simulation mode to play a crisis management game. (Such a use of the system would also provide personnel with opportunities to rehearse for real crises using the same tools they would have available to them in a real crisis.)

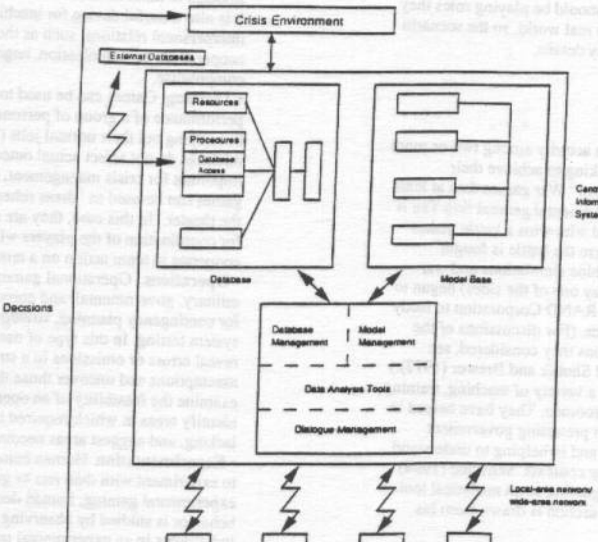

Figure 1 - Elements of a crisis management system

Based on the generic purposes for gaming given in the previous subsection, I can see three specific purposes for using gaming as a tool for improving crisis management:

1. To assist in pre-crisis resource requirements determination and resource allocation decisionmaking;
2. To assist in response planning;
3. To assist in training in crisis management for actual crises

However, gaming is a clumsy and unreliable tool for determining resource requirements and allocation decisions. Resource requirements and resource allocation depend crucially on the specific crisis situation. But scenarios and games are not meant to be predictive, so there is an extremely low probability of any given scenario coming to pass. Gaming is a better tool for response planning, and is best as a training tool. If used for these purposes, the focus can be on lessons learned that (to use the words of Schelling (Levine, Schelling, and Jones 1991]) "are not so particular as to depend on the locale of the crisis, the scenario chosen to initiate the game, the individual participants, or even the character of the crisis."

Based on their experiences in crisis games, Levine, Schelling, and Jones (1991) conclude that "the main beneficiaries of the game are the participants, and . . . in the case of participants in decision-making positions, the benefits are likely to be high." Thus, the game players should ideally be the same persons who will be in training, the players should be using the same support tools (databases, communications facilities, computers) that they would be using during the real crisis. They would then discover facts, ideas, possibilities, capabilities, and arguments that would be valuable for the real crisis (e.g., resource constraints, data availability, jurisdictional problems, standard operating procedures, relevant telephone numbers, etc.). Of course, their actions might still not be the same as they would be if the crisis were real, since they will not be experiencing the actual tensions and pressures. But having the CMS and operating it in real time should come close to reproducing the real situation.

Weiner (1968) describes what is involved in preparing, playing, and analyzing a game. The preparation phase starts with the definition of the purpose of the game. The purpose drives the specification of scenario required, the players to include, the data to prepare, and the analyses that will be done afterwards. Once the purpose is established, a scenario can be prepared, which must include the context (geography, location of resources, lines of communication, etc.) and the crisis (events before the start of the game, and exogenous events during the game). Having developed the inputs, the next major part of preparation is to develop the rules of the game. These rules include political restrictions, operating procedures, etc., that are the ground rules given to the players. They also include rules that will be used in the CMS (which will play the role of the controller or referee for the game) for estimating the effects that the players' actions will have on the system's performance. The CMS will use these rules to create the dynamic changes in the crisis situation to which the players will have to react over time.

Using the rules for the CMS, a simulation program must be written that will provide the game control. If the gaming use of the CMS has been thought of before the system is built, there will be built-in mechanisms that will facilitate the programming of the game. (In fact, many of the capabilities needed for the simulation will be required capabilities of the CMS.)

Once all of the preparatory work has been done, it is possible to play the game. As mentioned above, the players should be playing the roles that they would play in the case of a real crisis. The playing conditions should match as closely as possible the conditions that would exist in a real crisis. Play is started by a "briefing" to the players (perhaps via videotape), which describes the context and the events or conditions that led to the crisis. Then, the precipitating event is announced, and play begins. If serious confusion, errors, or arguments occur, the game can be stopped and restarted, but efforts should be made to finish the entire game without interruption.

When play ends, the analysis phase begins. Since the type of analysis that will be done is determined by the objective or purpose for which the game is being played, it is not possible to describe specific analyses without describing specific games. It is possible, however, to describe typical kinds of analyses. One type of analysis is outcome oriented. It examines what took place, and evaluates the performance. Positive and negative actions are noted, as well as actions that might have helped, but were not taken. The outcome-oriented analyses generally span the entire system and focus on *overall* effectiveness. There are also special analyses that focus on a single aspect of game play. For example, an analysis might be made of the actions of one particular agency (with the game replayed several times, to look at various alternative strategies for that agency). Another reason for replicating play might be to look at the effects of changing the resource allocation or information availability. An analysis might also be made of the behavior under stress of the various players.

Note that these analyses do not solve problems; if anything, they define new ones (e.g., holes in the system, missing information, inaccurate data in databases). It is also not necessarily true that if something happens in the game world, it will happen in the real world. As Levine (1991) warns, "the seductiveness of gaming is such that it is all too easy to turn hypotheses into conclusions." He then gives the following advice:

> "Game if you will. But in presenting policy results, don't tell anyone that you gamed. Present it in essay, model, or other analytical form without mentioning the game. If it is convincing in this form, then the game has been as good an instrument as any. If it is necessary to fall back on game "evidence," however, then the whole process is of very doubtful validity."

One follow-up to a game might be specifying a field test to reduce uncertainty as to the validity of the game's results.

CONCLUSIONS

The above discussion suggests that scenarios and gaming can play a useful role in crisis management planning and training. In particular, recent developments in information technology and telecommunications afford an opportunity to use these methodological tools in ways that were not previously possible. In the past, games were extremely expensive to stage, and took a great deal of time to play. Because much of the work had to be performed manually, very few "moves" could be carried out. If an existing CMS were able to be used offline to support the game, many of the game's support requirements would already exist, and most of the work that had to be carried out manually could be automated. Operating in real time, crisis managers can use the computer systems, databases, and communication channels that they would have to use in an actual crisis situation. The marginal costs are likely to be relatively small, and the potential benefits large. The time is ripe to try such a creative, state-of-the-art approach.

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BIOGRAPHY

Dr. Walker is a Senior Policy Analyst at the European-American Center for Policy Analysis, which is an office of the RAND Corporation that is located in Delft. He has been applying models to policy problems since 1969. Between 1969 and 1975 he was at The New York City-RAND Institute, where he was engaged in the development and use of mathematical models of the operations of urban emergency service departments. His chief concerns were with improving the deployment of fire companies, police patrol cars, and ambulances. Most recently, he has been working on a freight transportation project whose objective was to identify policy changes that might be able to reduce the negative effects of freight traffic on the roads without endangering the economic benefits that accrue from these activities. He recently co-authored a book entitled *Building Organizational Decision Support Systems* and a chapter for a book on ethics in modeling. He has been on the faculty of Columbia University and the RAND Graduate School, a consultant to the Solid Waste Management office of the U.S. Environmental Protection Agency, editor of the Public Sector Applications Department of *Management Science*, a member of the Los Angeles Productivity Commission, a member of the National Fire Protection Association's Committee on Public Fire Service Organization and Operations, and a member of the Editorial Review Board of *Fire Technology*.

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NATURAL DISASTERS

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ASSESSING STRUCTURE IGNITIONS IN THE WILDLAND/URBAN INTERFACE

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KEYWORDS: wildland/urban interface, risk assessment.

ABSTRACT

Major wildland/urban interface (WUI) fire losses, principally residences, continue to occur. Although the problem is not new, the specific structure ignition mechanisms associated with WUI fires are not well understood. The Structure Ignition Assessment Model (SIAM), currently under development, assesses the ignition risk of residences in relation to the WUI situation.

SIAM uses an analytical approach that relates the potential for sustained structure ignitions to the location and characteristics of adjacent fires and the structure's materials and design. SIAM's ignition risk assessment is based on a worst case estimate of the direct effect of flames leading to ignitions as well as ignitions from burning embers (firebrands). Initial SIAM results indicate that the flames of burning vegetation are not greatly effective in creating sustained ignitions. This suggests that firebrands and adjacent burning structures are significant causes of structure ignitions. Current experimentation is directed toward verifying these SIAM results.

THE WILDLAND/URBAN INTERFACE FIRE PROBLEM

Significant residential fire losses associated with wildland fires have occurred worldwide in recent years. The wildland/urban interface (WUI) or intermix refers to residences or vacation homes located in areas that are subject to wildland fires. The WUI fire problem is principally a property and life safety issue. This property and life safety consideration has taken priority over other more traditional wildland fire management concerns in the wildland/urban interface.

Demographics trends in the U.S. (Davis 1990) reveal an increase in the number of people who will reside in or adjacent to wildland areas, further increasing the WUI problem. Without mitigation, WUI losses are sure to continue or increase.

Commonly, severe WUI fires quickly involve many structures. Rapid fire growth in vegetative fuels commonly results in a fire front threatening numerous structures simultaneously and, most importantly, raining firebrands (burning embers) down on homes over a wide area. Advances in equipment, training, incident command systems, and multi-agency coordination, have produced the most effective firefighting capabilities in history. Yet these advances have not stemmed the increasing trend in WUI fire losses. A severe WUI fire can destroy whole neighborhoods in a few hours--much faster than the response time of the best fire services. For example, in October, 1993, the Laguna Hills fire in southern California destroyed nearly all of the 366 homes lost within 5 hours. This tendency of WUI fires to overwhelm fire suppression capabilities is often at odds with what society expects from fire protection.

The characteristic property losses during WUI fires differ dramatically from average residential fire losses. The 1991 U.S. residential fire loss statistics (including the Oakland, California fire losses) illustrate the characteristically higher WUI fire losses. Of the 1991 total residential fire occurrences, WUI fires account for less than .6 percent of the occurrences; however, WUI fire losses resulted in 27 percent of the property losses (Karter 1992). This reflects the higher fire losses per residence for WUI fires as compared to typical residential fires. During a WUI fire, ignited homes typically result in a total loss. For example, news media coverage of the WUI fires (Fleming *et al.* 1993) in the Laguna Hills of southern California show a few relatively unscathed houses adjacent to widespread, complete destruction. Partially damaged residences are the exception.

People often use terms such as "miracle" or "luck" to describe how some homes survive amid the destruction of their neighbors. These words imply helplessness, a lack of control, and a detachment from responsibility. While this may accurately describe the emotional states of those who just experienced wildfires, the assumption that homeowners cannot decrease fire losses is incorrect. Chance or "luck" does play a part in home survival, but the chances for home survival can be significantly improved with attention to WUI fire safety.

IGNITION ASSESSMENT FOR IMPROVING STRUCTURE SURVIVAL

What we observe after a WUI fire is, in varying degrees, structure survival. The degree of survival results from a complex, interactive sequence of events involving the ignition and burning of vegetation and structures, accompanied by varying fire protection efforts by homeowners and firefighters. The development of an assessment method requires an explicit description (at some resolution) of the processes involved.

Structure survival involves factors that influence ignition; and, if an ignition occurs, structure survival also involves factors that influence the fire suppression. Thus, structure survival assessments require consideration of the suppression effectiveness. Analysis reveals that the factors influencing suppression effectiveness greatly depend on the real time situation, thus making a prior description of the suppression factors unrealistic (Cohen 1991). Figure 1 diagrams the general process leading to structure survival or loss. As the figure illustrates, the structure survival process must "pass" through the occurrence or nonoccurrence of an ignition. By analyzing the ignition factors, and thereby improving ignition resistance, one can improve the chances for structure survival.

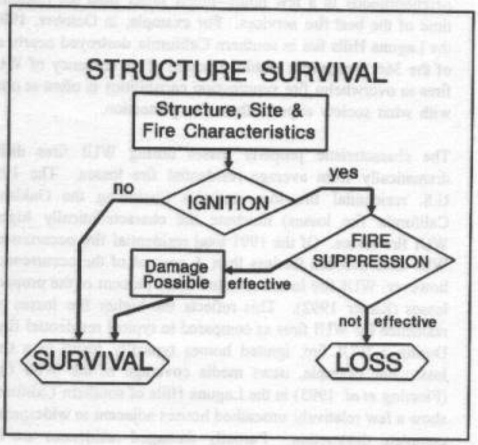

Figure 1–Structure survival depends on factors influencing ignition and factors influencing effective fire suppression. Regardless of the fire suppression effectiveness, survival initially depends on ignition.

The Structure Ignition Assessment Model (SIAM) is based on the premise that structure survival is the essence of the problem, and that structure ignition is the critical element for survival. That is, homes that do not ignite, do not burn. SIAM specifically addresses the potential for structure ignitions rather than the potential for structure survival.

THE STRUCTURE IGNITION ASSESSMENT MODEL (SIAM)

SIAM assesses the potential for structure ignitions during wildfires burning in vegetation and structures. The Model uses general descriptions of the structure, the topography at the building site, and the potential fire characteristics around the structure to compute an index of ignition risk. It is designed to provide a flexible approach toward achieving residential fire safety. That is, SIAM rates the potential for ignitions based on a structure's ignition resistance characteristics and its potential fire exposure. Thus, homeowners and developers can "tradeoff" various design features of a building's exterior and its surroundings to meet prescribed fire-safe requirements.

SIAM is intended for the facilitation of improving fire safety as well as for identifying potential WUI fire problems. In its basic form, the Model applies to a variety of applications from existing single home assessments to planned developments. The basic model applications can include:

- o A means for local regulators to establish fire safety requirements based on potential ignition risk for a mix of factors.
- o A means for integrating a resident's exterior home design and landscaping interests with fire safety requirements.
- o A means for integrating a developer's home and neighborhood design interests with fire safety requirements.
- o A means for fire agencies to assess WUI fire risks for pre-suppression and suppression planning.

To achieve these applications, SIAM uses an analytical approach to establish relationships between the structure design and the fire exposure that results in the assessment of potential ignitions. Since actual fire conditions of a future fire are unknown, worst-case assumptions are used. For example, it is not known how and in what sequence the flammables around a structure will burn; therefore, it is assumed that all flammables adjacent to the structure will burn at the same time. Also, a worst-case assumption regarding fire protection is that no fire protection will occur (a common occurrence during severe WUI fires). Where ignition processes are not explicitly understood, e.g., firebrand (flying embers) exposure and ignition, judgements based on physical reasoning are used. Because of the various unknowns, SIAM rates only the potential for structure ignition; it does not predict ignition.

A better understanding of the SIAM processes and my analysis of WUI structure ignitions can be obtained by examining the Model's components. Figure 2 diagrams the general processes from the input of information to the output of the resulting ignition risk rating.

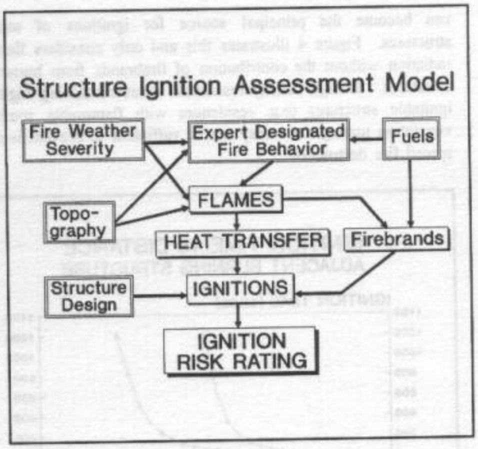

Figure 2--SIAM uses the inputs (double line boxes) to calculate the potential for ignitions from direct flame exposure and burning embers (firebrands). SIAM produces a dimensionless ignition risk rating index, not a prediction of ignitions.

The Model consists of six principal processing steps (items in the brackets refer to figure 2):

1) [Expert Designated Fire Behavior, Fire Weather Severity, Fuels, Topography, Structure Design]
SIAM inputs require the collection of the structure and site conditions that affect the potential for ignition. The Expert Designated Fire Behavior is the fire professional's estimate, from experience and/or calculation, of the flame length and rate of spread. This estimate considers and is consistent with the inputs for the Fire Weather Severity, Topography, and Fuels. The Topography, Fire Weather Severity, and Fuels also influence other factors such as the flame geometry, flame/structure geometry influencing convective and radiative heat fluxes, and firebrand characteristics. The Structure Design inputs relate to the general design, e.g., roof flammability, exterior materials, windows, nooks and crannies, and exterior dimensions.

2) [FLAMES]
Based on the input information of the fuel type, the fuel locations and the fuel length/width dimensions, windspeed, topographic slope, and flame lengths, FLAMES calculates the direct flame effects. Calculations include flame size, flame angle, burning residence time, and the structure/flame geometry. These factors determine the structure's potential exposure to flame radiant heating and flame or convection column contact. Flame sources, i.e., FUEL inputs, include neighboring structures.

3) [HEAT TRANSFER]
SIAM uses a physical heat transfer model to relate the calculated flame characteristics to the radiative and convective heat transfer. The heat transfer model calculates the incident heat transfer rather than the net heating at the structure's surface. Worst-case assumptions are used for the explicit description of such items as the flame temperature, the flame/wall geometry, and the variables influencing convective heat transfer.

4) [Firebrands]
Explicit understanding of firebrands and resulting structure ignitions does not exist. Using physical reasoning and experience, I assume that the firebrand exposure depends on the amount and size distribution of the firebrands generated. The firebrand exposure corresponds to the type of fuel (firebrand characteristics) and the fire intensity (lofting characteristics).

5) [IGNITIONS]
An empirical model (Tran *et al.* 1992) relates incident heat flux at a wood surface over time to the potential for piloted, sustained ignitions (pilot ignition--material is heated such that a small flame or hot spark can induce flaming; sustained ignition--flaming continues after the initial heat source is removed). SIAM calculates the influence of firebrands on the ignition potential based on firebrand exposure [Firebrands], the structure design, and the amount of heating from flames. The Model recognizes the potential effect of flame heating on firebrand ignitions. Structure heating from flames that is insufficient for ignition nevertheless, may enhance the potential for firebrand ignitions.

6) [IGNITION RISK RATING]
The rating process begins by assessing the ignition potential from flames and firebrands for each significant structure side and the roof covering. These assessments are then combined for the entire structure. The final rating is a dimensionless quantity, linearly related to potential structure ignition.

SIAM RESEARCH RESULTS

SIAM is currently under research and development and not ready for operational ignition assessments. However, the component models for heat transfer and ignition have been assembled and run, and experiments have been performed. The research results consider the effectiveness of flames as a radiant heat source for the ignition of wood walls, and the potential for thermally induced window breakage. The following summarizes the modeling and experimental results. Cohen (in press) provides more explicit information on the basis for the findings.

Flame Caused Ignitions

Preliminary SIAM results suggest that ignitions from vegetation flames occur from fires within the immediate surroundings of the structure. Except for the case of large flame heights and an extensive flame width, figure 3 indicates that ignitions result from flames within 15 meters of the structure. Initial laboratory testing with "large" flames (3 m high, 1.5 m wide, .8 m deep) and a wood surfaced wall section concurs with the SIAM results. However, ignitions on structures and adjacent vegetation commonly occur while wildfires burn at distances too far to be caused by flame exposures. This suggests that another factor is highly significant in structure ignition--firebrands. These results support personal observations that firebrands are a significant source for structure ignitions.

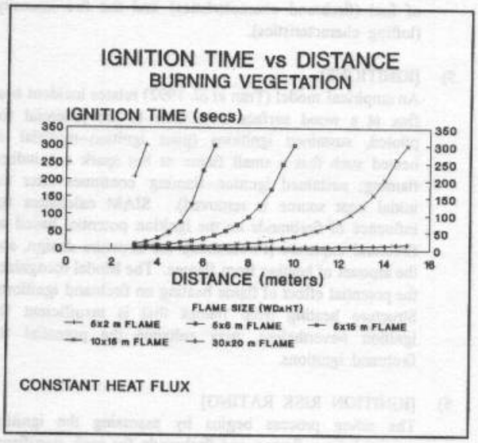

Figure 3–The SIAM heat transfer and ignition models generated these ignition times based on vegetation flame dimensions shown. Typically, vegetation fuels have flaming residence times less than 120 seconds.

This SIAM research suggests that for reducing ignitions, vegetation management beyond some relatively short distance from a structure (vegetation and topography dependent) has no significant benefit for reducing flame generated ignitions. And, vegetation management cannot be practically extensive enough to significantly reduce firebrand ignitions. Thus, the structure and its immediate surroundings should be the focus of activities intended for improving ignition risk.

Vegetation is often the focus of WUI mitigation actions, but in higher density residential areas, neighboring structures are a significant potential ignition source. SIAM results suggest that at distances between structures of less than 5 meters, structures can become the principal source for ignitions of other structures. Figure 4 illustrates this and only considers flame radiation without the contribution of firebrands from burning structures. In high density residential areas containing highly ignitable structures (e.g. residences with flammable roofs), vegetation management may not be sufficient to prevent wide spread fire destruction.

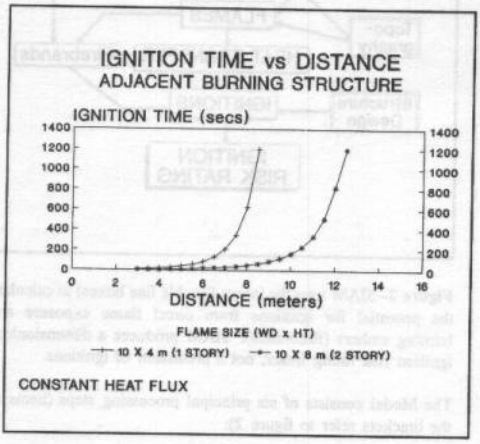

Figure 4–These SIAM generated ignition times are based on a totally involved burning wall of an adjacent structure. The flame is the same in the size as the wall and burns for 20 minutes.

Window Breakage

The structural fire problem regarding windows involves the fracture and subsequent collapse, thus leaving an opening. In the WUI context, firebrands are a very important structure ignition source. Experience indicates that any opening to the interior of the structure increases the potential for ignition. In the SIAM context of ignition assessment, windows are an important factor principally if a fire exposure results in a window fracture and collapse without a concurrent exterior ignition.

The experiments examined plate glass and tempered glass in single pane and double pane arrangements. The preliminary results indicate the following:

- o Single pane and double pane plate glass windows fractured and collapsed at heat flux/time exposures well below those necessary for piloted ignitions for wood. Thus, plate glass windows, particularly single pane, become a significant ignition risk factor.

- Significant differences were found between plate glass and tempered glass. At the same exposures, no tempered glass window fractured. Tests have yet to be completed for determining whether tempered glass will remain unfractured until wall ignition. However, the completed tests indicate that tempered glass has nearly the same resistance (in terms of heat flux/time exposure) to thermal fracturing as a wood wall has to piloted ignition.

- Window pane size influenced the potential for window collapse. Two sizes of glass were tested. For .61 by .61 meter panes, no collapse occurred after fracturing, even with inducement; however, 1.52 (vertical) by .91 (horizontal) meter panes collapsed. For each exposure level, breakage resulted in at least one window spontaneously collapsing and collapse was easily initiated for those that did not spontaneously collapse.

- The experiments showed that interior ignitions from flame radiation through a glass window (without breakage, during WUI fires) are highly unlikely. The plate glass windows broke and collapsed well below a heat flux/time exposure that would produce an ignition at the inside glass surface. Data extrapolation for tempered glass indicates that a wood exterior will ignite before ignition would be possible at the interior glass surface.

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EXPERIMENTAL STUDY OF FOREST FIRE

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KEYWORDS : Fire, Propagation, Hydrocarbon, Vegetable.

ABSTRACT

The aim of this study is to determine the influence of the four following parameters on a fire spread : voluminal mass and moisture of the fuel, slope and wind respectively in the ranges 8-40 kg/m3, 10-60%, 10-30% and 0-7 m/s for a vegetable fuel and of the wind and thickness for a hydrocarbon.

The results show that in these intervals of values voluminal mass does not play a significant role. The high moisture of a fuel delays and even stops the spread of the fire when there is no wind while the wind and the slope accelerate the spread of the flame front.

All the experiments have been performed mainly in the BEST canal but also in the TEXAID tunnel on excelsior for slight variations of the parameters. Other experiments will have to be carried out in order to verify the fire behaviour for wider intervals of values.

INTRODUCTION

This work has been achieved in the frame of the European MINERVE project.

The aim of the experiments carried out in the BEST test canal is to observe the spread phenomenon of the flame front over a vegetable fuel with respect to several parameters.

During this first study the voluminal mass, the slope, the wind and the moisture of the fuel have been studied separately.

Regarding the spread study according to the density the voluminal mass ranges between 8 and 40 kg/m3.

Regarding the study of the slope effects, four out of the eight carriages have been lifted by means of a frame and five slopes have been worked out : 10; 15, 20, 25 and 30%.

Several wind velocities ranging between 0 and 7 m/s have been tested in the tunnel for a constant mass per carriage.

Different methods for moistening the fuel have been applied to obtain fuel moistures ranging between 10 and 60%.

A study of the spread on a hydrocarbon has also been carried out in order to study the influence of both the pool thickness and the wind on the spread velocity of the flame front.

EXPERIMENTATION

Test facility

The BEST test canal : The BEST is an open test facility made up of an aeraulic module and a combustion one. The combustion module consists of two cellular concrete walls, which are 8 m long, 2 m high and 1 m apart. Between these two walls two containers have been put on rails ; they are 4 m long, 80 cm wide, 20 cm deep and subdivided into 4 comportments.

The TEXAID tunnel (Issartel *et al.* 1989) : It is made up of an aeraulic module, a combustion module whose dimensions are 0.4* 1.2 m² and a shaft module.

Experiment with a homogeneous fuel

The spread measurements have been tested with the TPH+TBP hydrocarbon (hydrogenated TetraPropylene 70+ TriButylPhosphate 30) ; it is a reference fuel for the spread in a homogeneous environment in the BEST canal.

The experimental apparatus consists of thermocouples, fluxmeters, a video camera and a heat camera. The liquid is kept in a steel container (3*0.60 m²). The experiments have been carried out for two different heights of fuel : 0.5 and 1 cm and for three winds whose intensity ranges between 0.2 and 4 m/s.

The flame temperatures are in the order of 800-900°C and do not vary with the thickness. The flame is about 1.2 m high. the flame velocity increases sharply with the wind but is stable with the thickness. The radiated heat fluxes increase markedly with the wind which tends to flatten the flame. The fuel height affects mainly the duration of combustion. The results are given in the table below :

wind intensity m/s	fuel height cm	spread velocity cm/s
0	0.5	3
	1	2.5
2	0.5	6
	1	5
4	0.5	11
	1	17

For 0.5 cm of fuel the spread velocity is slightly higher than obtained for 1 cm concerning the first two winds. However for a wind whose intensity is 4 m/s, the spread velocity obtained for 1 cm of fuel is superior to that obtained under the same conditions for a wind with half this intensity. The difference with regard to the 0.5 cm-fuel experiment is due to the outside conditions. As a matter of fact, an adverse wind of about 2 m/s had disturbed the spread and therefore has markedly decreased the velocity of the flame.

The flame spread over a hydrocarbon pool is sharply accelerated by the wind but seems to be very little affected by the variation of the fuel thickness.

Experiments with excelsior

Excelsior is a dry fuel quickly implemented.

Density (Naville et al. 1994)

Various voluminal masse ranging between 8 and 40 kg/m3 have been chosen to study the spread of the flame front with respect to the density.

The temperatures and the flame height have remained stable during all the experiments, respectively 800°C and 60 cm.

The spread velocity can be considered like the value constant : 1.5 cm/s. This constant kinetics can be attributed to a slight variation of the percentage of air trapped in the curling for the different voluminal masses.

Comparison between TEXAID and BEST

The spread velocities obtained in the two test facilities are constant whatever the voluminal mass can be. Therefore the exterior disturbances peculiar to the BEST do not seem to modify the spread phenomenon.

The velocities obtained in the TEXAID and in the BEST vary by a factor of two. This difference is not attributable to the different dimensions of the two test facilities, if one refers to the experiments carried out in Portugal by the University of COIMBRA. It must be due to the airing in the open test facility, as it contributes to the combustion reaction and consequently increases both the spread velocity and the flame temperatures.

However the flame heights remain appreciably identical.

Considering the elasticity of the curling the voluminal mass does not play a significant role during the spread phenomenon in the range 8-40 kg/m3. Accordingly a necessary mass of about 500g/ carriage has been accepted for the forthcoming experiments.

Slope

In order to study the spread of a fire over an inclined surface, five slopes ranging between 10 and 30% have been worked out by means of a frame which enables the last four carriages to be lifted.

The flame temperature and the combustion duration do not vary with the slope for all the experiments, while the spread velocity increases sharply.

The first four carriages are not lifted, whatever the experiment is. The following carriages are lifted and the spread velocity increases exponentially with the slope in this part.
Throught these velocity measurements the acceleration between the plane section and the inclined one has been calculated and shown in figure 1.
The spread velocity increases sharply with the slope, just as the radiated fluxes recieved by the fuel vary by a factor of two between the plane part and the inclined one.

Comparison BEST-TEXAID

The absolute spread velocities obtained in the TEXAID for a voluminal mass of 16 kg/m3 and a fuel moisture of 12% are similar to those obtained in the BEST.

The spread velocity of an ascending fire increases markedly with the slope.

Wind

For a constant fuel density of 12.5 kg/m3, several experiments have been carried out with winds ranging between 2 and 7 m/s.

There are important variations in the spread velocities according the the day when the experiment was carried out. Therefore the results given are in absolute velocity (figure 2).

The reference velocity is defined for every day by the spread velocity of the fire without any wind or slope for the same fuel density.

Between 2 and 5 m/s, the spread velocity increases markedly then it lessens between 5 and 7 m/s.

The spread of the flame front increases sharply with the ventilation, but there seem to be stages.

Moisture

In order to study the effect of the fuel moisture on the spread of the flame front the non-moistened curling (moisture 10%) has been tested :

. soaking of the fuel : the moisture of the curling reaches 60% (maximum moisture) and through drying it decreases to 40% ;

. night humidity : it allows the fuel moisture to reach about 60% (mainly on the surface) and through drying it decreases to 27% ;

. artificial humidity : low water contents are obtained, between 15 and 20%.

When it is not windy a humidity ranging between 40 and 60% is too high to enable the fire to spread. In order to observe the spread of the flame front with respect to humidity a wind has been added to accelerate the drying of the fuel.

The results given in figure 3 are in absolute velocity (the reference velocity is the spread velocity in the first four carriages).
The spread velocity decreases markedly in 1/x when the fuel moisture increases.

A high moisture of the fuel can strongly slow down and even stop the spread of the fire when there is no wind. This restricting factor connected with an aggravating factor such as the wind looses much of its efficiency. As a matter of fact the wind dries up the fuel on the surface.

CONCLUSION

The study of the four parameters, that is to say the slope, the wind, the density and the moisture of the fuel has shown that :

. in the 8-40kg/m3 range, the voluminal mass of the fuel does not play a significant role,

. in the 0-30% range, the slope increases the velocity of the flame spread,

. in the 0-7 m/s range, the wind accelerates markedly the spread of the flame front,

. when the moisture is 60%, the spread of the flame front stops. By connecting the humidity and wind factors, the flame spreads, even when the moisture is almost at its peak.

The behaviour of the spread velocity according to the wind velocity is similar to that observed with regard to the slope. The effects of the wind and the slope on the flame are practically identical ; they consist of flattening the flame on the fuel, thus increasing the tranfers of radiative energy for the slope case and the tranfers of both radiative and convective energy for the wind case. Therefore the results are in good agreement.

Other experiments on a larger scale of values for these four parameters will be performed in the next series of tests, in order to verify the behaviour observed during these experiments.

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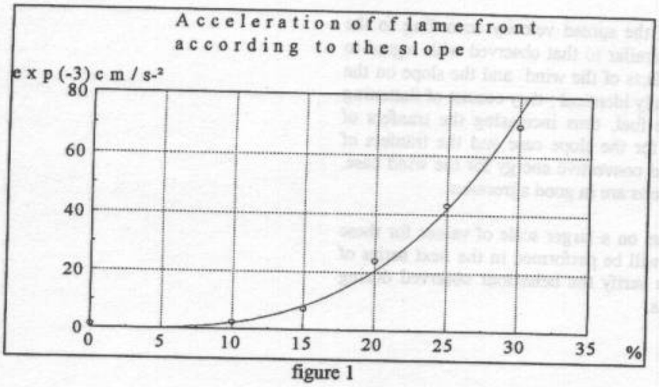

figure 1

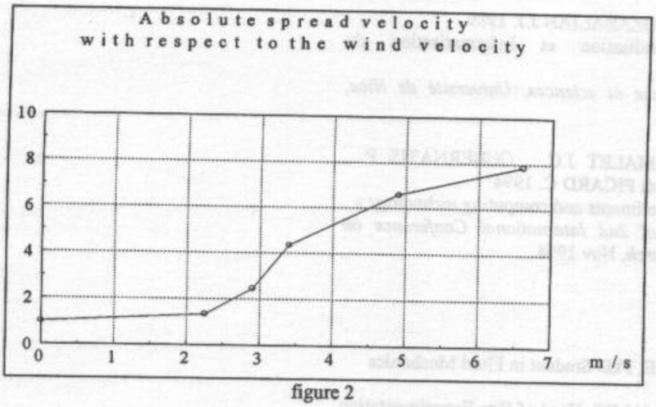

figure 2

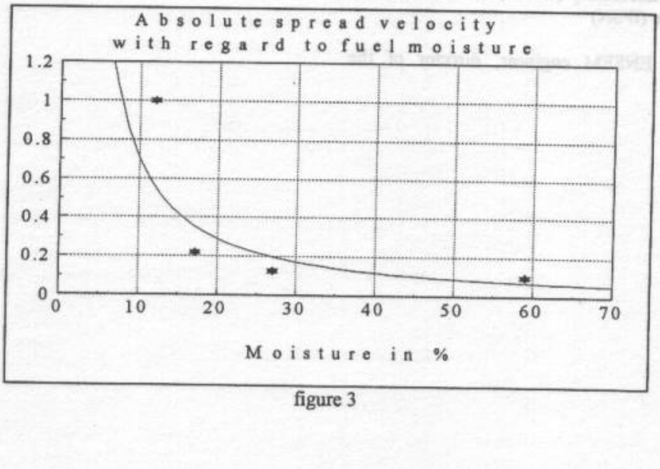

figure 3

EXPERT KNOWLEDGE AND QUANTITATIVE WIND MODELLING FOR SPATIAL DECISION SUPPORT DEDICATED TO WILDLAND FIRE PREVENTION

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KEYWORDS: wildland fires, expert knowledge, quantitative model

ABSTRACT

The objective of this study, carried out as part of an European Union contract, has considered in elaborating an aid package that enables "automatic" and "real time" identification of the instantaneous wind situation during seasons with high forest fire hazard.

INTRODUCTION

Meteorology is one of the major components of wildland fire behaviour. In order to provide a better forecast of the wind field and thus to have a more realistic wildland fire behaviour prediction, we present a new approach for wind modelling.

Traditionally, wind behaviour modelling tends to use **quantitative models**.We use such a model, called Nuatmos (Ross & al., 1988). After simulations with real data, several insufficiencies were noted. We decided to use **expert knowledge on meteorological situations** to improve quality of results. Thus it was agreed that **the link of a quantitative model** with an **expert analysis** is an alternative to make up for the lack of satisfactory results.

Three research teams are involved in this project. The mathematical wind model study is leaded by the Cermics, the expert analysis is provided by P.Carrega (topoclimatological specialist), and finally, the knowledge-based system design, implementation and its integration in a Spatial Decision Support System dedicated to wildland fire prevention are done by Ecole des Mines.

QUANTITATIVE AND QUALITATIVE APPROACHES IN THE WIND MODELLING CONTEXT

Research Background

The problem of wind modelling is basically related to the need of having an estimation of the wind field in different geographical locations and for different weather conditions. Meteorological parameters have a decisive role in the outbreak and spread of wildland fires. Wind, relative humidity and air temperature are, in particular, directly measurable and can be studied individually or collectively. In our case, they are combined in order to generate meteorological hazard indices and inputs for fire behaviour models. They can be also used to give to managers the essential information concerning the wind speed and direction in a region of interest.

Located in southeastern France and exposed to a Mediterranean climate, the Alpes-Maritimes Department is an area of mountainous relief with a relatively dense network of weather sensors. This area is covered by 21 meteorologic sensors. They record temperature (°C), relative humidity (%) and wind (the direction from 0° to 360° and the speed in m/s). The sensors are questionned by modem three times per day or more if needed during high risk periods in summer. All the data acquired are stored and managed by a Relational Data Base Management System (R-DBMS) and and maps of the different fields are computed and stored in a Geographical Information System (GIS) in order to have a spatial distribution of the phenomena.

Usefulness Of A Mathematical Wind Model

The wind behaviour study is based on data measured in several points (the sensor network).This discrete spatial data is often insufficient. A global wind field estimation for the total geographical area is needed. For this, we must use more or less sophisticated models which allow a reconstitution, in all points of the space, of the wind intensity from some point data. This problem recovers from the interpolation values. It is solved using mathematical models.

In this context, we use such a model. The diagnostic model NUATMOS produces a three-dimensional mass-consistent wind field in complex terrain based on wind observations (velocity and direction).

First, an interpolation of observed data is performed to produce an "initial" wind field over the whole domain of interest. Measurements at 10 meters provided by the sensor network are used. In a second step, the resulting wind field is ajusted to satisfy mass-conservation by minimun possible modification. Mathematically, the problem is to minimize the functional

$$\int_D \left[\alpha_1{}^2(u - u_o)^2 + \alpha_1{}^2(v - v_o)^2 + \alpha_2{}^2(w - w_o)^2 + \lambda\, \vec{\nabla}.\vec{U}\right] dV \quad (1)$$

where (x, y, z) are the terrain-following coordinates, $\vec{U} = (u, v, w)$ is the velocity, $\overrightarrow{U_o} = (u_o, v_o, w_o)$ is the initial interpolated wind field, α_1 and α_2 are positive parameters (Gauss precision moduli) and λ is the Lagrange multiplier of the constraint of mass conservation $\nabla . \vec{U} = 0$.

After derivation, the Euler-Lagrange equations to be solved are then:

$$\left| \begin{array}{l} 2\,\alpha_1{}^2\,(u - u_o) = \dfrac{\partial\lambda}{\partial x},\; 2\,\alpha_1{}^2\,(v - v_o) = \dfrac{\partial\lambda}{\partial y},\;\; 2\,\alpha_2{}^2\,(w - w_o) = \dfrac{\partial\lambda}{\partial z} \quad (2) \\ \\ \qquad\qquad\qquad\qquad\qquad \dfrac{\partial u}{\partial x} + \dfrac{\partial v}{\partial y} + \dfrac{\partial w}{\partial z} = 0 \end{array} \right.$$

which can be manipuled to give:

$$\frac{\partial^2\lambda}{\partial x^2} + \frac{\partial^2\lambda}{\partial y^2} + \frac{\partial^2\lambda}{\partial z^2} = -2\,\vec{\nabla}.\overrightarrow{U_o} \quad (3)$$

The following coordinate transformation is made

$$\overline{x} = x,\ \overline{y} = y,\ \sigma = \frac{z_\iota - z}{z_\iota - z_s} \quad (4)$$

where the subscript ι denotes the top of the solution domain and s the terrain surface. The equation (3) is written in these new coordinates and the obtained Poisson equation is solved iteratively using a tridiagonal solver and an elaborate differencing scheme. A Multi-Grid method which employs more than one nested grid is used in order to speed up the convergence.

Days representing typical meteorologic situations were selected in order to compare three main features (Carrega P. & al., 1994):

- the general behaviour of the wind field on the studied domain,

- at each sensor, the deviation between the measured value and the value given by the models, for the velocity and the direction,
- the variation over all sensors of the directions and velocities estimated by the model.

For typical situations when the wind field is locally strongly influenced by the topography (as in a valley for instance), the behaviour of the computed wind field is acceptable only if sensors by their location are representative of the meteorologic situation. This is not the case, in particular, for valleys, where an "upstream" flow takes place during the day: without a sensor inside the valley, this flow is completely ignored by the model (the error reaches in certain cases 90° for the wind direction).

Wind Types Identification And Expert Analysis

To improve the behaviour of the computed wind field, we decided to add virtual sensors in several valleys. The values of the direction and the velocity were estimated for **different identified meteorological situations** following the method provided by a topoclimatological expert.

Four months (February 1991, February 1992, July and August, 1992) were chosen for the treatment of the data provided by the network of meteorological sensors. Two sets of measurements, taken at 03:00 H and 15:00H GMT, and representing respectively the nocturnal and diurnal regimes, composed the bulk data retained for analysis.

The main problem consists, on one hand, in establishing a typology of the situations; the parameter combinations which are adapted to the issue (which is not the case of the usually elaborated climatologic typologies) and on the other hand, in being able to automatically identify the actual weather, exclusively from the weather sensors data.

The wind types are defined on the basis of discrimination between breeze and synoptic regimes (Carrega P., 1994). A combination of inductive and deductive procedures, partly used a verified existing model and sought to define their local applications. The situations and the behaviour of the stations have been analysed from a succession of steps of reasoning involving the crossing of several type of information:

- detection of types of situation from Principal Component Analysis's of wind speed,
- analysis of the dealy weather situation for day from synoptic charts and collection of all available weather parameters,
- complete, individual and fine analysis of each situation allows to associate wind direction and speed with each representative sensor.

A total of 6 wind types were defined for each season. To each type corresponds an expected effect at each sensor, that is a wind behaviour type depending on the type of situation and the type of local topography. For each type, the expert elaborated a set of rules in order to identify automatically the wind type, already classified for its specific behaviour.

We give an example with rules proposed by the topoclimatologist in order to identify a general breeze regime (at 15:00 GMT):

. If at Ascros, the wind has a directional range of 100°-170° with a speed of 4-7 m/s; and if at Mandelieu, 70°-120° or 210°-230°, with 3-6 m/s; and if at Breil, 160°-200°, 2-7 m/s; and if at Caussols, 120°, with 1-6 m/s; and if at Menton, 130°-160°, with 0-2 m/s; and if at Levens, 180°-260°, 1-2 m/s; and if St Roman, 160°-190°, with a speed of 1-4 m/s, then general breeze regime.

. If no breeze detected at Mandelieu, and wind speed ≤ 6 m/s and ≤ 4 m/s at Tanneron, and breeze elsewhere, then general breeze regime.

. If no breeze detected by a maximun of four out of seven sensors, but wind speed < rule (especially if ≤ 2m/s), then general breeze regime.

Soundings made out of the sampling context confirm the validity of the types adopted in this study. We must note that the construction of the rules pursued two phases: they were first made over one month only, summer and winter alike, and night and day alike. The second month is used as verification, and showed that only a few minor modifications had to be made.

At the end of this step, the idea to use virtual sensors in order to improve the results calculated by the mathematical model occured. Our objective is to add to the set of initial data (the sensor network) several virtual sensors with data provided by the topoclimatologist. For each wind type previously identified, the expert is able to indicate the better location for several virtual sensor and to give their probable values.

HOW CAN QUANTITATIVE AND QUALITATIVE MODELS BE USED TOGETHER IN A SPATIAL DECISION CONTEXT?

Toward A Mixed Approach

The coupling of qualitative and quantitative models is now widely recognized to be an effective means of addressing many computing problems in science, engineering, business and environment.

There are several factors that are generally involved in the choice between a qualitative and a quantitative model (Hulthage, 1988). Some reasons to choose a qualitative model are based on the non satisfactory results of existing quantitative models, on the insufficiency of input data in order to use such models and on their computational difficulties. Some reasons to choose a quantitative model are based on the fact that it can give sufficient accuracy and it is known that it is fast enough and applicable in all relevant cases.

Therefore, it is clear that qualitative reasoning cannot replace quantitative reasoning or vice versa, but rather they complement each other.

How The WILFRIED System Deals With This Original Approach Of wind Modelling?

The WILFRIED system (Guarnieri, 1995) is an integrated SDSS (Spatial Decision Support System) designed to fit the requirements of managers in charge of wildland fire prevention and fighting. In the same computer software, the system proposes a relevant set of tools (Data Base System, Geographic Information System, Simulation models, User Interface). In order to help the user in his decision-making job, the system offers several functions allowing him to manipulate and visualize geographical data and to make WHAT-IF analyses on fire behaviour or on danger assessment for a critical meteorological situation using models for simulations.

We describe the way how the WILFRIED system provides a better prediction of the wildland fire behaviour or danger assessment by mixing the quantitative and the qualitative approaches of the wind modelling.

We describe the mixed approach:

- Firstly, meteorological data are collected by a modem. They are stored and managed by a R-DBMS and a GIS.
- Then, the system triggers the knowledge base "Pierrot" in order to identify the wind type and to locate the virtual sensors.
- Finally, the system triggers the Nuatmos model with all the collected data (real and virtual). The results (a wind speed map and a wind direction map) are stored in the GIS. At this time, the WILFRIED system is able to compute the other parameters needed for the prevention support. The steps are repeated for each set of new weather data.

Knowledge-Based System

In this part, we explain how we have formalized the expert knowledge using the knowledge-based system approach.

An knowledge-based system can generally be divided in two parts: the knowledge base composed of facts and rules, and a program intended to apply the rules to the facts according to a given context. This program called inference engine is independant of the knowledge base. The initial prototype was implemented starting from the expert analysis (see § 1.3) and several other documents (texts of the interviews) which detail:

- the facts: describe the state of the problem,
- the rules: fixing the logical inferences.

We use a classical formalism called "production rules" :

IF <condition1> <condition2> ... <conditionN>

THEN <assumption1> <assumption2> ... <assumptionN>

This expression may be translated by:

IF condition1 is true and condition2 is true and ... and conditionN is true

THEN we may deduce that assumption1 is true and assumption2 is true and ... and ... assumptionN is true.

We give an example with a rule proposed by the expert:

IF Mandelieu 220°, ≥ 5m/s and if Saint Roman 130°-160°, 3-6m/s and if Antibes 190°-220°, 3-6m/s and if Mont Agel 240°-290°, 2-6m/s and if Sophia-Antipolis 160°-210°, 2-5m/s

***THEN* Synoptic type S.**

Thus, programming with rules consists in defining all the knowledge bricks allowing the solution of the problem without any concern of the initial arrangement of these different bricks. The inference engine, acting as a bricklayer, selects the bricks and sets them to the best to solve the submitted problem.

The knowledge base "Pierrot" contains all the knowledge accessed by the system at a given time of the processing in order to continue it. This knowledge is formalized by situation descriptors (assumptions, corresponding to the conclusive (i.e., THEN) part of the rule and the data, corresponding to the rule premiss (i.e., IF) and by production rules. The fact and the rule bases constitute the knowledge base grouping the knowledge set of the studied domain. The fact base is constituted of declarative knowledge, static and descriptive, characterizing the concepts properties or the objects and their relations. This base must contain all the facts that the system has to deduce at a given time (example of facts in the base "Pierrot": the wind direction and the wind speed). The rule base contains the different operating knowledge types. It indicates the way to use the facts, roughly simulating a reasoning fragment or a way to act. It is the part of the system in charge of bearing all the studied domain knowledge.

The knowledge base "Pierrot" deduces the wind type and can give to the user a commentary explaining the wind behaviour. Once the weather type has been determined by the knowledge-based system, it is necessary to give a value at the virtual sensors (wind direction and speed). The expert analyses the daily data and deduces the values which will be assigned to the different sensors. This knowledge forms a second knowledge base.

After the identification of a breeze situation, three virtual sensors are added (see fig 1 and 2) in three valleys. The values of the direction and the velocity are estimated. The system runs the Nuatmos models with added data. Figure 2 shows the inportant role of these virtual sensors for this meteorologic situation. Now, the wind flows throught the valleys, taking into account the topography.

CONCLUSION

This project gathered people from universities (Nice-Sophia-Antipolis) and research centers (Cermics and Ecole des Mines), having very different approaches of the wind phenomena modelling. The first one, in this case P.Carrega, is acquainted with the studied area and of the topoclimatologic phenomena. The second (Cermics) are numerical modelling specialists. Encountering with insufficiencies of the Nuatmos model, combined with the lack of sensors in characteristic locations, the idea to use the expert's work on wind type identification was retained. Realizing validation tests on the Nuatmos model, the hypothesis to use virtual sensors was put forward. Thus, it was agreed that the link of a quantitative model with expert knowledge was the solution to obtain satisfactory results. Tests and validation simulations are realized in order to verify these hypothesis.

ACKNOWLEDGEMENTS

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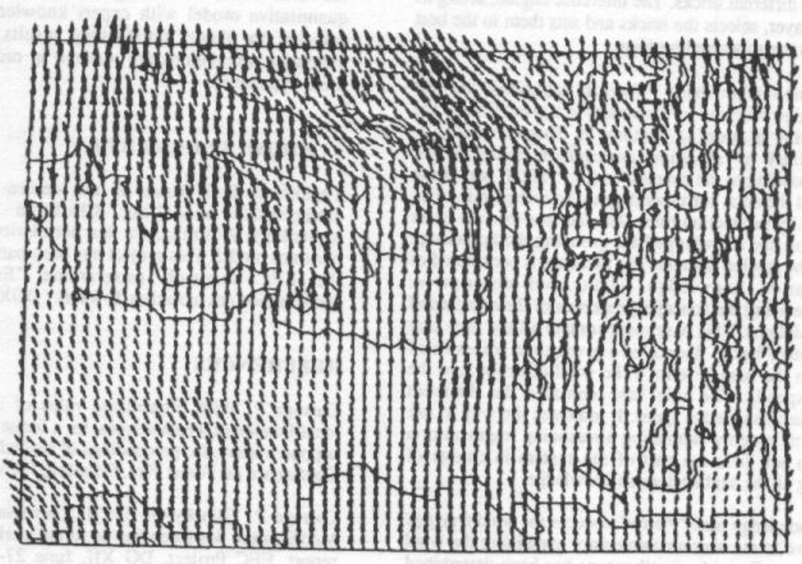

Figure 1: Wind field computation without the three virtual sensors

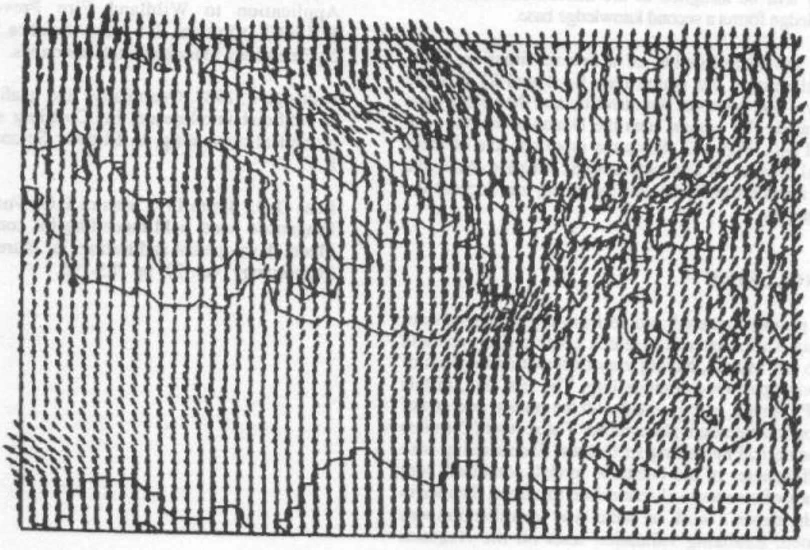

Figure 2: Wind field computation with the three virtual sensors

Fires

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USE OF EXPLOSIVES AND TORCHES FOR LAVA FLOWS DIVERSION VOLCANIC ACTIVITY SIMULATION AND FIRE FIGHTING

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KEYWORDS: volcano simulation, fire fighting , lava flow diversion .

ABSTRACT

In 1983 on Mt Etna we had the opportunity to divert lava flows: exploding the lava levee. Since that time we have developed a new method which is now operational. In order to perfect our knowledge of volcanic activity and lava flow behavior we developed the know-how of making it possible to create a small experimental volcano. The technologies developed to explode lava flows can be applied in extinguishing wild well oil or gas fires.

THE HISTORICAL BACKGROUIND:

Different attempts have been made to prevent destruction due to lava flows.

Pouring water or building artificial barriers delayed the lava front advance, but none were entirely successful.(Jaggar 1936;1937;1945; 1949; Mason and Foster 1953; MacDonald 1958; Williams and Moore 1973; Bolt *et al.* 1975; Kilburn 1983; Colombrita 1984).

More efficient techniques have been applied to disrupt the feeder tube systems.

In Hawaii in 1935 and 1942 the United States Air Force and volcanologists decided to attempt the diversion of a lava flow by bombing lava tubes. The bombing was found to be effective in breaking the cover of a tunnel or side of a small crater, but it lacked precision, especially when visibility was poor. This method can be ineffective when there is no suitable area to where the lava could be diverted, as in Kapoho in 1960, where the only protection was to build earth barriers (Jaggar 1936; Lockwood and Torgerson 1980).

MODERN TECHNOLOGIES:

Complete success has been achieved two times in arresting a lava front : in 1983 and 1992 on Mt Etna. In both cases the lava was diverted at the lava source, the molten rock being driven into a new channel, cooling faster in the open air, and covering the already solidified lavas of the same eruption. Both diversions were obtained using explosives: 390 kg in boreholes removed 200m3 of rocks on May 14, 1983; more than 7000 kg placed on the surface of the soil removed 50 m3 on May 26, 1992 (Abersten 1984; Barberi and Villari 1984; Lockwood and Romano 1985; Barberi *et al* 1993).

In both cases the initial diversion was only 30 to 40% just after the blast. During the following hours big blocks of rocks completed the work, obstructing the lava tunnel down slope. In 1983, they fell in the channel naturally; in 1992 they had been prepared in advance using an excavator with an hydraulic jackhammer and a bulldozer.

WASTING TIME:

On Mt Etna in 1992 a long time was wasted flying concrete blocks by helicopter, experimenting with big explosions on the surface of the lava flow, sinking iron crosses and iron chains in the active lava flow, and building earth barriers across the lava flow. The advantage of using surface placed charges despite the enormous quantities needed, was to avoid drilling and the need to cool the explosives in the high temperature bore holes heated by conduction from the active lava (Barberi et al. 1993).

These spectacular interventions were completly inefficients for the following reasons:

- the cross section ot the lava tunnels was 3 to 4 times larger than the concrete block size.
- armored concrete blocks are not refractory , they broke when heated in the lava
- the asbestos insulation of the iron chain delayed but did not prevent the temperature increase of the metals.
- surface explosions already tested in 1983 are inefficient as they don't affect the bottom of the burried lava flows

The 7000 kg of explosives placed on the surface of the soil the 26 of May were necessary even if the rock diaphragm to explode was only 3m thick.

THE NEW METHODS

Taking advantage of the 1983 experiment we proposed a new project based on drilling methods to the Italian civil defense on December 4, 1991 and submited it to the Commission of the European Communities in January 1991.
In both cases it was rejected.

The advantage of drilling can by listed as follows:
1- minimum waste of explosive energy toward the atmosphere;
2- explosive charges can be placed as close as necessary to the active lava, and at any depth;
3- blasted rocks and blocks can be produced at the site, and obtained to any depth and in large quantities of more than 1000 m3 per day using the up-to-date techniques;
4- explosives confined in rows of holes easily produce big blocks of refractory lava, while in contrast, surface charges pulverize the rocks, and bloks have to be produced away from the site, transported, and sunk in the lava channel;
5- modern boring techniques make it possible to both drill and install the tubes;
6- bore holes could have a diameter up to 180mm making possible to load as much as 40kg of explosives per meter at any depth;
7- boring equipments and compressors can be transported by helicopter even if the weight of the heaviest equipment is more than 6000 kg
8- excavators, buldozzers, drilling machines and explosives have already been used or tested on lava flows or wild wells burning oil or gas.
9- the field camp for the personnal can be quickly put up on site and the work can go on even in case of bad weather during the operation. (In 1992 the intervention lasted for 47 days, 15 days being lost for bad weather as poor visibility prevented the helicopter from bringing the operators in the field).
The total time necessary to complete an intervention with our new method was assessed to be 14 days: 7 days to prepare and set the field equipments, 7 days of field work including drilling and exploding.

EXPLOSIVES AT HIGH TEMPERATURE:

When drilling in 1983 we measured up to 900°C in the bore holes. Cooling was necessary in order to prevent deterioration or uncontrolled detonation of the explosives. Different cooling methods have been designed
1) Water cooling jackets. Water stored in a big reservoir circulates in a double wall tube, keeping the temperature below 60°C in the hole (Rodio system) (Volpe and Tonoli 1984)
2) Air guns: this method was designed by the Swedish technician Rune Gustafsson and is based on the principle of the Flobert compressed air gun. It makes it possible to load explosives from a distance using a pneumatic system.(Abersten 1984)
These first two methods were used in 1983, about half of the 55 holes being equipped with each. before detonating.This method saves water cooling and the amount of compressed air needed is minimal.

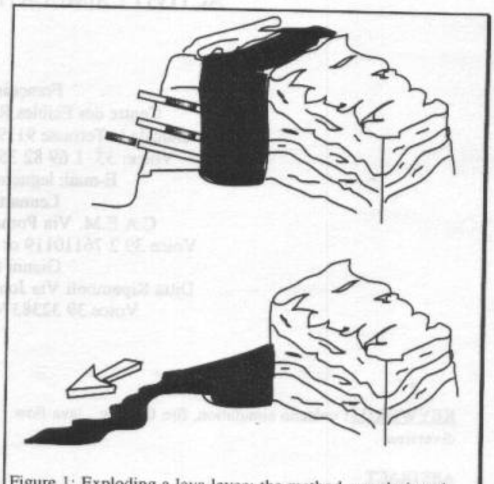


Figure 1: Exploding a lava levee: the method was designed and used in 1983: explosives are placed in horizontal bore holes. Water jacket or air guns prevent the deterioration by the heat transfer from the lava.

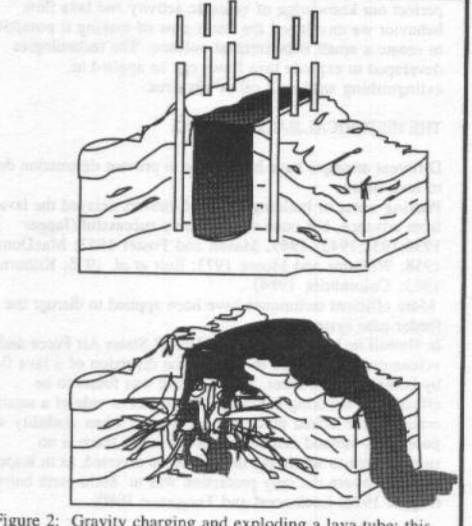


Figure 2: Gravity charging and exploding a lava tube: this method has not been tested in real size.

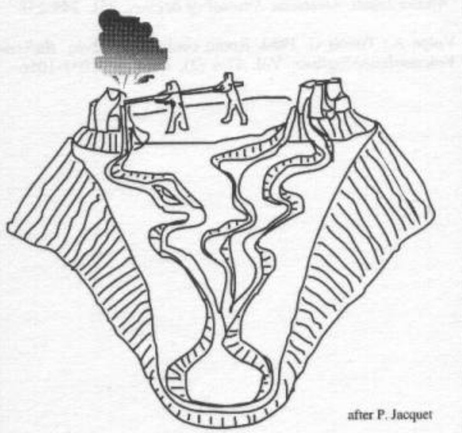
3) Gravity charging: This method was designed but had not yet been applied . Explosives are charged in vertical tubes overhanging the hot bore holes. Small pistons keep them suspended outside. A few seconds before blasting, compressed air removes the pistons, and charges fall in the hole just

THE ERUPTION SIMULATION

The project submitted to the Commission of the European Communities in January 1992 contained different testing methods:

- lava cutting using high pressure water
- lava melting using high temperature torches
- molten lava exploding by water injection

In order to perfect our knowledge of lava flow behavior a team of chemists, volcanologists, movie makers, and plastic art teacher supported by The "Gerland Company" supported a complete experience of artificial lava flow simulation in a basaltic quarry located in the Centre of France. Fusion was obtained by oxidation of iron tubes in pure oxygen. After different tests in the workshop and in open air the team succeded to create a small lava flow and a 1 m3 lava empoundment. Lava casts were also successfuly made.



after P. Jacquet

Figure 3: Experimental workshop as operated in Ardèche (France)

Analyzing the mother rock by the K, Ar dating method gave an age of 13 10^6 Years. The fused rock had a zero effective age as it was nearly completely de-gassed. During and after the test the fusion gases were collected and analyzed. They contained carbone dioxide, sulfur (as sublimate) and chlorine 150 to 300 mg/m^3. Many flames were observed on the lava surface. A small lava deviation was made by fusing the lava levee. The artificial volcanic activity is very similar to the same kind of phenomena observed on real volcanoes. This know-how already applied in cleaning fires or cuting reinforced concrete.makes it possible to design a "Small volcano laboratory" in order to simulate and study lava flows, magma de-gassing and gas differentiation in the soil and atmosphere. We could also test the effects of explosives on representative volumes of molten rock

FIRE FIGHTING WORK ON BURNING GAS OR OIL.

Tested in Kuwait, it is possible to approch a flamme 15 to 20 meters high, 1500 to 1600°C, as close as 3 to 4m (soil temperature 120°C at 20m). The approch was made with asbestos "COMASEC" equipments free of cooling air or water (Le Guern 1991).

Two methods have been developed and tested. They gain time and security during the capping and fire-fighting work:

Method 1: Cutting and cleaning of casing and/or well-head by means of remote control diamond-equipped devices.Total cutting of the casing takes about 2 hours.

Besides total cutting, we can also cut and take away the outside casing tubes, leaving the inner tube (in Kuwait 18cm in diameter) to be capped on, with specially built equipment.

Method 2: Utilization of explosives to weld a tube, possibly equipped with a closing valve, above the well-head. Welding by blasting has been done on surfaces flushing with petroleum, and has been tested to withstand at least 300 atm. The explosive charges can be placed in a special container (2 halves to put together outside the tube) which can be cooled by circulating water according to the know-how developed on lava levee disruption..

The tube being welded, the flow of petroleum or gas can be estinguished by closing the valve (Figure 4).

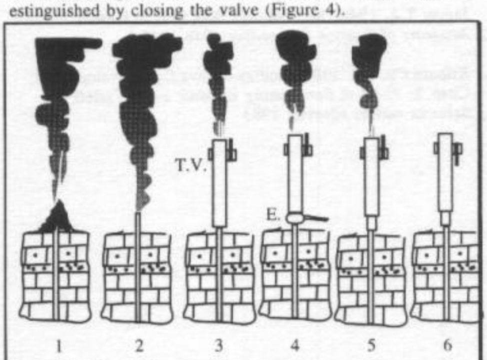


Figure 4. Fire fighting procedure:
1: Initial situation: the destroyed well head is surrounded by debris and solid silica condensation.
2: Cleaning and cutting with a remote control diamond equioed device.
3: tubing
4: blasting welding
5: the tube after blasting welding: pressure resistant to more than 300 atm.
6: stop fire and control
T.V.: Telecommanded Valve.
E.: Special container for explosives with water circulation system.

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USE OF THE *FARSITE* FIRE GROWTH MODEL FOR FIRE PREDICTION IN U.S. NATIONAL PARKS

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KEYWORDS: fire modeling, fire simulation, wildland fire, geographic information systems.

ASTRACT: The *FARSITE* (Fire Area Simulator) is a fire growth model that spatially projects fire perimeters and behavior over complex landscapes. The model uses spatial data themes from a geographic information system (GIS) along with weather and wind data to propagate fire as a spreading wave front. The model runs on a personal computer under the WINDOWS operating environment. Version 1.0 of the *FARSITE* model was distributed by the US National Park Service and US Forest Service beginning January 1995. Its intended use is for management support of active fires and planning for potential fires.

We used *FARSITE* in support of fire management decisions regarding naturally ignited fires at Yosemite National Park, California, and Glacier National Park, Montana during the Summer of 1994. The fire growth projections were used for deciding if fires should be suppressed or allowed to burn under management supervision (termed "prescribed natural fires"). Model output was compared against spread patterns from previous fires at Glacier, Yosemite National Park and Sequoia National Parks. The general features of the observed spread patterns and fire behavior were in reasonable agreement with the model projections, given limitations of available data on fuels and weather. The applications and early validations suggest that accurate data on fuels and winds are crucial to model performance, but that the model is a useful tool for management of wildland fires.

INTRODUCTION

Wildand fires are common to forest and rangelands of North America and increasingly in suburban areas near cities. Whether started by lightning or by humans, most fires are actively suppressed in attempt to avoid damage to natural resources or structures. Fires in the wildland urban intermix can have disastrous consequences, as recently demonstrated in the 1991 Oakland Hills Fire in Oakland California (2500 structures lost), and Colorado (1994, 14 fire fighters killed).

Despite the prevailing policy of fire suppression for most wildland areas, fire plays an important ecological role in many natural ecosystems that evolved with it. Fire maintains the presence of some plant and animal species as well as their diversity. Management objectives for maintaining ecosystems have led to a "prescribed natural fire" (PNF) policy that permits fires under pre-determined conditions to burn with limited hindrance on some lands. The two policies treat fires differently yet both require tools for long and short range fire growth projections. The relative lack of management interference with PNFs makes them an important source of information on fire spread and behavior that is critical to validating models of large fire growth. Fire growth models are useful for planning and management operations on both suppression fires and PNFs (Andrews 1989). In this paper, we describe a new tool for long-range fire growth projection, some example applications, and some lessons for further work in the applying fire growth modeling in fire management organizations.

BACKGROUND

Since the early 1980's, U.S. the Forest Service and other US land management agencies have used the BEHAVE fire behavior prediction system (Andrews 1986) for short term predictions of fire behavior and spread. The BEHAVE system was designed for short range projections (typically shorter than 24 hours) using site-specific information on fuels, weather, and topography (Rothermel 1983). It was not designed for long term projections or for large fire growth in a spatially explicit manner. Models of this type are referred to as fire growth models.

Computerized fire growth models have been described in the scientific literature since the early 1970's. Two basic deterministic approaches to modeling fire growth have emerged, cellular and wave-type models (Finney 1994). These approaches differ much like the methods used for representing landscape data in geographic information systems (GIS): raster versus vector. They also differ in the way time and space variables are used; cellular models rely on the fixed distance between cells to solve for fire arrival time at those cells. Wave-type models provide a finite time-step to calculate fire spread distance, inverse to the cellular models.

Raster models (e.g. cellular models) attempt to spread fire as a discrete process of ignitions between adjacent cells on a regular grid. Examples of this type of approach are numerous. The earliest effort by Kourtz and O'Regan (1971), has been followed by many other cellular models too numerous to mention here. This approach has some limitations, although methods do exist for mitigating their impact on fire growth simulation under relatively simple situations (French 1992). Fire shapes are distorted by the gridded geometry of the calculations, different arrival times at cells on the fire edge make temporal changes difficult to implement synchronously around the fire. Long computation times are required for these models.

Vector models treat fire growth as a spreading wave front (Anderson et al. 1982) meaning the edge of the fire is defined by an expanding polygon. A number of techniques for this have recently been published (Richards 1990, Knight and Coleman 1993, Roberts 1989). The first description of this idea applied to fire modeling was by Sanderlin and Sunderson (1975) for the FIREMAN project in Southern California. Anderson et al. (1982) brought the technique and terminology into the fire and forestry literature. The technique is now commonly termed Huygens' Principle in reference to the 17th century mathematician (Christian Huygens) who advanced theories on the travel of light waves. Compared to cellular models, vector based models are computationally efficient and allow a logical extension to 2-dimensions of the 1-dimensional point-vector models of fire spread and behavior (Rothermel 1972, Andrews 1986).

Although a variety of these models have been demonstrated as prototypes most have been confined to research purposes (Finney 1995). Reasons have included limitations on: 1) the power of computers for the required fast computation times, 2) computer availability to wildland managers and, 3) use and familiarity with geographic information systems (GIS) and/or data bases for managers. These restrictions are or have been overcome by the infusion of personal computers in all phases of land management and the proliferation of GIS capabilities and data bases.

DEVELOPMENT OF *FARSITE*

The *FARSITE* (Fire Area Simulator) model has been developed as a management tool for personal computers (Finney 1994, 1995). Personal computers with 32-bit operating systems are now capable of long term simulations. A user interface for the *FARSITE* model was developed for the WIN32s operating system and allows *FARSITE* to run in Windows 3.1x, Windows 95, and Windows NT. Other versions of *FARSITE* for UNIX operating systems are being developed.

Raster data themes required for the *FARSITE* model are elevation, slope, aspect, fuel model (Anderson 1982), and forest cover percentage. Richards' (1990) algorithm is employed for propagating elliptical waves. As with all Huygens' algorithms, the algorithm uses points on the fire's edge as independent sources of elliptical wavelets. The shape, orientation, and size of each wavelet is determined locally by the strength of the wind-slope vector as related to elliptical dimensions (Anderson 1982, Alexander 1985), the vectored wind-slope direction, and the fire rate of spread. The fire spread rate is determined by the local fuel type, fuel moisture conditions, and wind-slope vector using the Rothermel spread equation (Rothermel 1972, Andrews 1986).

Weather and wind data are also required for the simulation as two separate streams. The weather stream consists of temperature and humidity maxima and minima for a given day and elevation, and the hours at which these occur. A simple lapse rate calculation is used to adjust weather for different elevations. Temperature and humidity values for any time throughout the day are obtained by a sine wave interpolation. These are used to compute the suite of fuel moistures (Rothermel *et al.* 1986) required by the Rothermel fire spread equation. *FARSITE* computes fuel moistures for a given point on the fire edge at a given time by starting from initial conditions. This is much faster than computing fuel moisture values for all cells on a landscape at each timestep.

Wind data comprise a separate stream containing wind vectors at specific times; temporal variation in winds can be expressed to the nearest minute. In this version of *FARSITE*, winds are considered spatially constant for a given data stream and parallel to the ground surface at all locations. *FARSITE* allows multiple weather and wind streams to be employed for a given landscape. After loading multiple1 streams, the user can define a grid of arbitrary resolution and specify the cells for which a given stream applies. This is useful for distinguishing wind streams applying to ridgetops and valley bottoms.

USE OF *FARSITE*

The *FARSITE* model was used for fire growth projection on prescribed natural fires in the summer of 1994 during a testing phase. Tests were conducted in several U.S. National Parks: Sequoia and Kings Canyon and Yosemite in California, and in Glacier National Park in Montana (Figure 1). The primary purposes of the tests were to refine the graphical interface, to get feedback from users of the program under active fire management situations, and to evaluate the requirements for using the program as a field tool. Although actual validation of the model was not the purpose during the ongoing fires, data were collected to make later validation possible. Data on fire growth and behavior, weather, and fuel moisture were recorded routinely for all fires.

The fire season of 1994 in the western United States was relatively active. *FARSITE* was used on a number of fires at the test sites. Two fires in particular provided good opportunity for our tests because of their long duration and large sizes. The Horizon Prescribed Natural Fire at Yosemite (2000 ha), and the Howling Prescribed Natural Fire Complex at Glacier (5000 ha) each burned for several months between July and September.

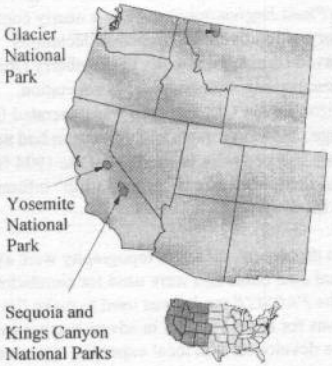

Figure 1. Map of western United States showing National Park test sites for FARSITE during summer 1994.

The Horizon PNF occurred between approximately 1500 and 2500 meters in elevation in the mountains south of Yosemite Valley in the Sierra Nevada of California (Figure 1). The topography is generally north facing and is dominated by granite outcrops that form ridges along the east and west boundaries of the fire. Manzanita chaparral (Arctostaphyllos manzanita), a relatively flammable evergreen shrub, generally grows on the thinner soils surrounding these outcrops and extends into the understory of sparse forests of Jefferey pine (*Pinus jeffreyii*), red fir (*Abies magnifica*), and white fir (*Abies concolor*) that border the chaparral. Denser forests between the outcrops including lodgepole pine (*Pinus contorta*) contain fuels more typical of a forest understory, having varying amounts of large woody material and conifer needle litter. These fuels were relatively easily distinguished from among about 30 spectral categories generated by classifying a satellite image from the Thematic Mapper (TM).

The Howling PNF occurred at approximately 600 to 1000 meters elevation in the lower montane forests of the northern Rocky Mountains of Glacier National Park (Figure 1). The topography at these elevations is moderately steep and facing west toward the North Fork of the Flathead River. Dense forests of ponderosa pine (*Pinus ponderosa*), western larch (*Larix occidentalis*), Douglas-fir (*Pseudotsuga menziesii*) and Englemann *spruce (Picea Englemannii*) contain a nearly continuous understory of relatively inflammable deciduous broadleaved shrubs, principally thimbleberry (*Rubus parviflorus*), along with herbaceous vegetation. As with the Horizon Fire, a GIS fuel map was generated from a TM image. However, fuels and vegetation had not been rigorously mapped prior to the start of the 1994 fire season so there was limited "ground truth" information to validate the map.

GIS data themes for fuels and topography were available from local data bases and were used for simulation of the fires. The *FARSITE* model was used to make fire growth projections for up to 1 month in advance using weather scenarios developed with local expertise. Two weather scenarios were developed for each fire. The first contained "normal" patterns of summer fire weather. This pattern was a composite based on expected typical and recent weather patterns and included high and low temperatures and humidities and typical diurnal fluctuations in wind speed and direction. The second scenarios punctuated this normal pattern with days of extreme fire weather. On the Horizon fire, this meant a strong foehn wind (known locally as a Mono wind) from the east with low relative humidities (15 to 25%) sustained for several days. On the Howling fire, extreme conditions are caused by the passage of late season "dry" cold fronts; winds come from the northwest for approximately 24 hours.

RESULTS

The simulations were more accurate for the Horizon fire than the Howling fire. However, the simulations proved to be useful to managers of both fires. Early projections of the Horizon fire verified conventional expectations for short term fire spread and suggested fire spread patterns weeks into the future that became regarded as reasonably accurate given the uncertainties about weather (Figure 2). The projections of the Howling fire suggested a rate and pattern of fire growth that was far more conservative than more subjective estimates made by local fire specialists (Figure 3). The differences between the fire growth projections led to reexamining the assumptions that contributed to the fire spread projections. The simulation results also suggested wider variability in fire spread than would have been considered during those early stages of the planning process.

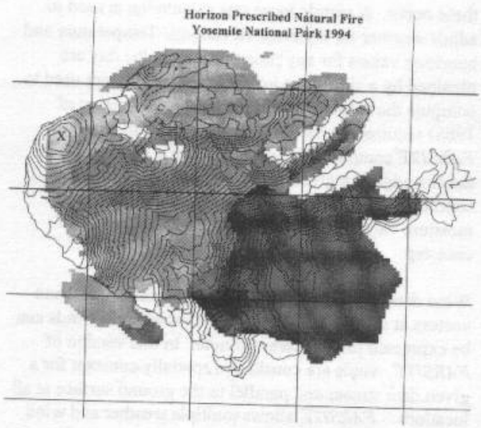

Figure 2. Fire spread patterns recorded for the Horizon prescribed natural fire at Yosemite National Park, California (shading), compared to daily perimeters predicted by the *FARSITE* model (lines).

The simulations of the two fires clearly showed the need for accurate fuel maps and descriptions. Based on several weeks of field reconnaissance, the fuels map produced for the Horizon fire was considered reasonably accurate. The fuel models were descriptive of the physical fuel characteristics as well as the fire behavior generated by the Rothermel spread equation. Timber and shrub fuel types were spatially distinct and burned with spread rates and intensities typical of those predicted. Consequently, fire growth and behavior was simulated to a useful degree of accuracy (Figure 2). Fire spread was generally slow through the forest understories and much faster through the shrub and grass fuels. Exceptions occurred on several days when winds increased and torched small areas of forest (20 ha) that contributed to spot fires approximately 1000 m ahead of the fire front.

Although the fuels map for the Howling fire appeared reasonable, the fuel models themselves did not translate accurately to fire behavior. The Howling fire spread primarily through smoldering or periodic creeping in the litter and dead woody material on the forest floor. Occasionally, spruce trees were torched and cast embers up to 50 meters ahead of the fire front (these often started new spot fires). The fire burning in the surface fuels rarely exhibited "typical" surface fire spread characteristics as required by the Rothermel model. The Rothermel (1972) spread model assumes that fuels are uniformly distributed at the spatial scale over which fire behavior is predicted. Although the shrub and herbaceous fuel layers were relatively uniform, these fuels were above the moisture limit for burning. As a result, the burnable fuel bed consisted of discontinuous pockets of dead forest litter, mostly near tree bases and along corridors of dead logs on the ground. At the scale of fire behavior experienced under the existing weather conditions the distribution of fuels in the howling fire violated the uniformity assumption in the Rothermel (1972) model. Fire behavior predictions strongly depend on the involvement of live shrubby fuels; faster spread rates and higher intensities result if shrubs are assumed *a priori* to be burning. This *a priori* decision is necessary because there are no methods for predetermining the transition of a fire to the canopy of a shrub layer when it is burning in litter. Live shrubby fuels can become available to the fire and contribute to fire spread only when moisture contents are low and densities high enough. These thresholds of moisture content and fuel continuity however, are not well understood.

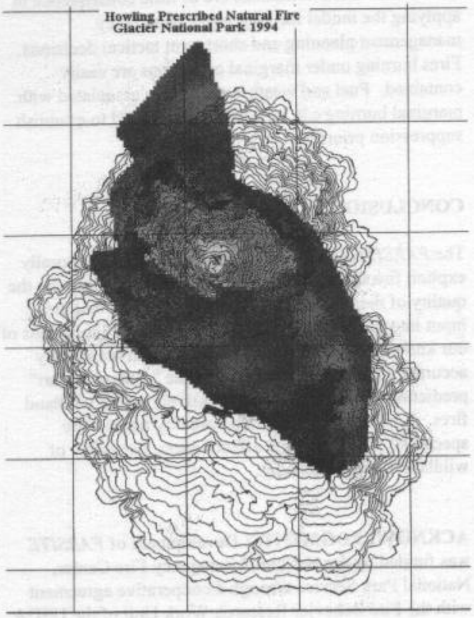

Figure 3. Fire spread patterns recorded for the Howling prescribed natural fire at Glacier National Park, Montana (shading), compared to daily perimeters predicted by the *FARSITE* model (lines).

RESEARCH NEEDS

Testing of the *FARSITE* model on the Horizon and Howling fires points to the need for additional basic research into several aspects of fire behavior. We currently have a poor understanding of how live fuels affect the spread and intensity of wildland fires. The average heat content of live fuels, ca. 19,000 kJ/kg ± 20 percent, is more than adequate to evaporate the moisture within these fuels but live fuels appear to retard fire spread and intensity until some threshold is reached. This threshold is probably related to complex heat transfer interactions between fire burning in the dead surface litter and the shrub and forest canopy. Fires burn poorly in densely packed dead surface litter, particularly when shaded and sheltered from wind such as was common in the Howling Fire. The amount of these fuels was greater beneath spruce canopies. When these fuels burned during low midday humidities sufficient heat was generated to initiate torching of the spruce canopies. Spruce foliage has a relatively high heat content, relatively low moisture content, and a relatively dense uniform fuel particle packing as compared with the deciduous broadleaf shrub canopy. Spruce canopies burned rapidly and intensely. However, these fuels were imbedded in a larger fuel matrix of relatively poor burning potential. The 1994 fire season was one of unusually high lightning occurrence and low precipitation in Glacier National Park. Several fires were ignited. Fires that burned in fuels dominated by dense coniferous forest canopies or uniform evergreen shrubs exhibited relatively uniform predictable spread rates and intensities as contrasted with the discontinuous spread of the Howling Fire. However, the one unusual factor in 1994's fire weather was the relative lack of high wind. In 1988 a nearby fire, the Red Bench fire, demonstrated that under high wind conditions fuels similar to those on the Howling Fire will burn rapidly and intensely (Bushey 1989). More basic research is needed to better understand how heat source versus heat sink relationships are affected by spatial and temporal changes in fuels as vegetation and weather change daily and seasonally.

There has been an active fire research program at Yosemite National Park for several decades. As a result there has been a considerable effort devoted to spatially mapping fuels. These data are indispensable to quality fire behavior predictions. However, they are costly and time consuming to obtain. Research currently being conducted at the Intermountain Fire Sciences Laboratory is aimed at developing a National Fuels/Vegetation map for regional fire planning (Burgan and Hardy 1994). This mapping efforts relies on spectral data from the Advanced Very High Resolution Radiometer (AVHRR) which has a 1 km spatial resolution. Also, research has demonstrated that AVHRR data can be used to monitor seasonal changes in the relative greenness, an indication of moisture status, of vegetation. While these data appear to be very valuable for large scale regional fire planning they lack the spatial resolution necessary for many fire applications. Additional research is needed to develop reliable methods for deriving fuel inputs to fire behavior prediction models such as *FARSITE*.

POTENTIAL APPLICATIONS

There are several potential applications of the *FARSITE* model both in long range fire management planning and in short range tactical decisions. Provided good spatial fuels and terrain data are available, *FARSITE* can be used to predict spatially explicit fire spread and intensity under multiple fire weather scenarios. Thus the model can be used as a gaming tool to simultaneously account for numerous varying factors affecting fire behavior. It also has potential as a tool for training fire specialists.

The predicted behavior of wildland fires is critical for deciding to allow prescribed natural fires to burn. Indeed this was the primary motivation for developing the model. *FARSITE* also has potential application in the suppression of wildland fires. In rugged terrain it is often necessary to attack the fire indirectly by constructing fire lines kilometers ahead of an advancing fire. *FARSITE* fire behavior predictions can aid in developing criteria for control line location and width.

In the wildland-urban interface *FARSITE* is a potentially useful tool for presuppression planning. Fuel inputs can be modified to evaluate the effectiveness of various proposed fuel management treatments. Fire behavior outputs can be compared to the values at risk to establish priorities for the safe effective deployment of suppression forces and to establish standards for development in the wildland-urban intermix. Once areas of severe fire potential have been spatially identified *FARSITE* can display the model inputs for such areas thus helping to identify common hazard elements (e.g., fuel type or terrain slope).

The limitations of the *FARSITE* model which were identified as a result of the Howling Fire are primarily limitations concerning using the model for projections involving extended durations and marginal burning conditions. Such limitations are of little consequence in applying the model for long range emergency management planning and short term tactical decisions. Fires burning under marginal conditions are easily contained. Fuel and weather conditions associated with marginal burning can be described and used to establish suppression priorities.

CONCLUSIONS

The *FARSITE* model simulates spatially and temporally explicit fire spread and intensity. It is limited both by the quality of the fuels, weather, and terrain data that are input into the model and by the fundamental limitations of our knowledge about fire behavior. Given reasonably accurate inputs the model can provide "state of the art" predictions of the behavior of relatively active wildland fires. *FARSITE* outputs can be used by trained fire specialists to improve the effectiveness and safety of wildland fire management.

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TOWARDS A NEW APPROACH TO FOREST FIRE

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KEYWORDS: wildland fires, fire danger assessment, large fires, conflagration, disaster.

ABSTRACT

Statistics show that in the past twenty years, there has been an evolution of the burnt surface of the wildland fires in the french mediterranean area. The number of small and medium-sized fires have decreased while the number of larger fires has increased. The larger fires are responsible for the major part of the burnt area today. They represent 60% of the burnt area compared to 33% twenty years ago. Prevention and firefighting means are efficient for smaller fires but are more limited in the fighting of larger fires.

This suggests a change or modification in both fire management and in risk studies. Basically, it seems important to study crown fires and conflagrations risk, in order to propose a new methodology which takes into account these changes, to improve the prevention and fighting of fires.

The goal of such methodology is to determine where fire managers can expect danger. The authors try to define these areas and in addition, such a methodology needs to take into consideration other area characteristics such as the environment, social and human characteristics (of an area involved with forest fires), or more precisely prevention measures and emergency priorities.

To reach these goals, researchers, territory managers and fire managers are working in partnership. This collaboration is necessary to propose quality models and to develop applied research.

INTRODUCTION

All regions all over the world with major forest fire problems have their own methods for dealing with this problem.
For example in the United States they have fought fires agressively for almost eighty years. For the last twenty years they have faced a changing ecosystem and an accumulation of fuel, because their system was adapted to fires.

To face this new problem they used prescribed fire and a "prescribed natural burn" policy in designate cases. After the well known Yellowstone fires, this approach has been almost abandonned.
As we can see, there have been a lot of changes in a relatively short period of time with continuing changes in the society.

In France we face an identical problem with accumulating fuels, but more importantly through social changes. Where the small farmers/herdsmen leave the mountains and their grazing fields turn slowly into highly flammable fuels, the city people leave their towns to live in the so called wildland urban interface. They do not introduce more fuel but a higher ignition risk for property and increase the priority for the resources needed in fighting the fire.

But all parties: foresters, home owners, fire fighters, politicians, ecologists, wildlife biologists... have their own different points of view and approach for this complex problem.

The goal of this paper is to emphasize some ideas for a better forest fire management. From statistics, we found out the new problems induced by forest fires and we propose both a new methodology and a new decision support system.

This paper proposes to help researchers to improve the knowledge on risk and danger, to catch the real problem for firefighters and managers and to improve the effectiveness and safety of wildland fire management.

FROM WILDLAND FIRE TO CATASTROPHE

Some Figures And Ideas

The statistical analysis of the situation indicates that frequency and damage of wildland fire represent one of the most important disturbances for the mediterranean ecosystems.
The protection of this patrimony is an important preoccupation with 2,2 millions ha of forest in the french mediterranean area (4.2 millions ha wildland of which is 2 millions of landes, garrigues and so on).

Some observations can be established from wildland fire statistics. They show that in the past twenty years an average of 40000 ha has been destroyed by fires which correspond to 4000 starting points.
We notice both a small decrease in the number of starting points and a stability of the total burnt area, in spite of the urbanisation, the surrender of the agricultural area, and the growing area of forested land.
These positive results (compared to the other mediterranean countries) can be explained by the efficiency of the communication and firefighting.

However, we have noticed an evolution in the characteristics of fires. The number of small and medium size fires (1 to 500 ha) are decreasing. On the contrary, large fires (more than 500 ha) represent a growing part of the burnt area: 57 per cent today against 32 per cent ten years ago.

Another change also appeared in the time period in which the fires burned. Now, most of the burnt areas were concentrated in four or five days as opposed to fifteen days, fifteen years ago.

The analysis of these figures permits several observations:

- in the lower cases (small fires), we notice few evolutions, both in burnt area and number of starting points

- in the intermediate situations, the progress is significant and the average burnt area is divided by two

- the worst cases show an opposite situation and the average burnt area is multiplied by two

- most of the fires are controlled sooner, but the few fires which occur in the period of high meteorologic risk involve a larger surface

So prevention and fire fighting have a positive effect on the intermediate situations but are deficient in the worst cases, where we notice an increase of surface burnt.

Different explanations can be found:

- fire fighting is more difficult today because the forest is a growing area and the wildland urban interface complicates fire fighting

- the efficiency of fire fighting in normal cases contributes to increase danger in exceptional conditions where the fires involve a high quantity of fuel

A paradox appears: prevention and fighting actions contribute to preserve biomass and accumulation of fuel. At the same time, the danger of large fires is increasing in the coming years, with the increase of the fuel load.

The Paradox

The progress only represents a delayed effect. The reduction of the normal danger leads to an increase of the exceptional danger. The success obtained in recent years contributes to increase the fire danger and the probability of larger burnt areas.

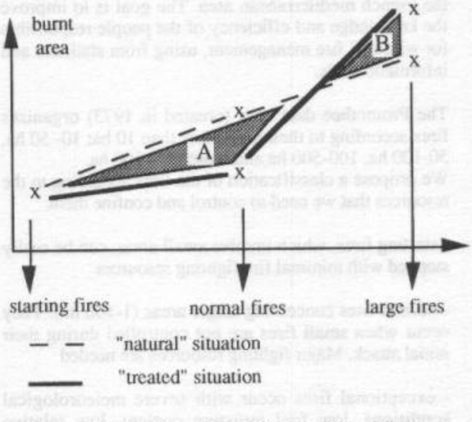

figure 1: Evolution of the different kinds of fires

To improve the fire prevention and fighting, It would be interesting to evaluate the values of A and B

If A situation, which represents a profit (compared to "natural" situation without intervention and preventive actions), is more important than B which is a deficit (opposite effect of the efficiency of the firefighting), it means an advancement and we have to go on fighting fires in the same way.
If A an B are more or less equal, we can wonder whether it is interesting to work towards this end.
If B is more important than A, it is necessary to change management. It means that we must try to live with fire and not require its elimination. Besides, the use of decision support system and danger analysis has to be considered.

Accordingly, we can consider fire as a natural event (as an element of the ecosystem), and we can choose not to fight the fire and let it go its natural way.
This does not seem logical with the close proximity of forest and urban areas. Moreover the limits of such policy are reached when the damage caused by the frequency and the intensity of the disaster is greater than the capacity for regrowth of the biomass and involves a change in vegetation.

This study indicates that one of the most important aspects of prevention and fighting of wildland fires is the size of the fires and our capacity to prevent and control them.

How To Classify Fires ?

A database, named Promethee, studies wildland fires in the French mediterranean area. The goal is to improve the knowledge and efficiency of the people responsible for wildland fire management, using from statistics and informatic tools.

The Promethee data base (created in 1973) organizes fires according to their areas: less than 10 ha; 10- 50 ha, 50-100 ha, 100-500 ha and more than 500 ha.
We propose a classification of the fires according to the resources that we need to control and confine them:

- starting fires, which involve small areas, can be easily stopped with minimal fire fighting resources

- normal fires concerning larger areas (1-100 ha). They occur when small fires are not controlled during their initial attack. Major fighting resources are needed

- exceptional fires occur with severe meteorological conditions, low fuel moisture content, low relative humidity, strong winds and high temperatures. In these cases, we can see an important number of ignition points in no time, both in wildland-urban interface and forested areas, which indicates an expansion a spreading of the firefighting resources because of the importance of protecting people and structures

It would be significantt to determine the areas where such a disaster may occur. The authors took into account the spatial variability of danger and also analysed the origin of the danger in order to find the relation between the prevention and the variables of the threat.

This analysis needs to be updated in accordance with the evolution of the "value" of the wildland areas, the use or social observances that people make in wildland areas.

THE FIRE DANGER

Fire danger is often defined as a general term expressing the result of both constant and variable factors which affect the chances of a fire starting, spreading, doing damage, and its difficulty to control.

The Danger Parameters

The identification of the danger parameters is a stage in the danger analysis and decision support. We can classify these parameters in two categories: human factors and environmental factors.

The human factors are linked with fire occurence

- land use (housing concentration and dispersion, road network)
- land managment
- activities (industry, tourism, rubbish dump)

In this case, the human factors are associated with the causes of fire and not as an effect of fire on man as we can see below.

The environmental factors, associated with spread of the fire, include three kinds of parameters which concern:

- fuel: nature, morphology, continuity, arrangement, flammability of vegetation
- weather: aspect, elevation, slope

- climatology: wind, precipitation, relative humidity, temperature

A Methodology For The Danger Analysis

A fire danger analysis requires taking into account the indicators of danger and the definition of the areas affected.

The Indicators

For a reliable analysis of a large fire, it is necessary to know the value of the parameters of danger and the relationship between them, in order to adapt the firefighting plans. The authors propose a particular methodology for this kind of disaster and to notice its indicators.

The number of severe fires is relatively independant of the number of days with a high danger. Only one day can produce significant result: severe meteorological risk is only one of the conditions in the occurence of a large fire.

This observation is important because large fire occurence depends on the land use, the fuel density and arrangement, the organization and the firefighting plans.

Many areas correspond to these situations, and we can try to identify them. We can establish a "potential" danger of fire in the frame of different risk parameters which could include:

- the location of an area in comparison with a forest clump. An area can be threatened, only threatened if ignition is in its territory, or in one or several bordering ones

- the accessibility of an area (in the sense of the intervention capacities) characterized by the topography, the location of the emergency centers, the road network density...govern the control of the phenomenon (knowing there is no danger when the burnt area at the moment of the intervention is less than 1 ha). A classification of these areas allows us to register the most dangerous conditions

- the high risk days when the meteorological conditions can provoke large fires in a particular area

- the pressure of ignitions (fire events, statistical history), which is an indicator of the part of human factors in the occurency of large fires

The Areas

We obtain for each area an indicator of having a large fire in relation to the history of this area (Promethee data base). We can constitute several kinds of threatened areas:

- the most sensitive and threatened forest belts. The danger of fires is at the top. The only thing we can do is to prepare to fight the fire

- the forest belts which are less sensitive but are threatened by large fires. The danger is significant and the prevention, the surveillance and a quick intervention can be important solutions

- the boundaries of the forest belts (which are very sensitive lands) with a high and constant pressure of starting points. Human life and structures are the most important focus of the rescuers. The danger is significant and the focus is to try to limit the effects of fires

- The urban areas where the danger is high because of demographic pressure. Here, prevention is the best solution

- the more dense areas, less sensitive. The danger is low

DISASTROUS FIRES AND CONFLAGRATIONS

There are two kinds of large fires according to social and scientific points of view.

According To The Impact On The Social Life

A fire which destroys agriculture crops, houses, natural lands, human life is a disaster by its consequencies on social and economic activities. Most of the time, these fires concern the wildland-urban interface.

This fire danger results from both demographic and technological factors and overlay natural lands and urban areas. The boundaries between them concentrate most of the starting points which can become a conflagration and/or a disaster.

The evaluation of the wealth, owned or shared by the different areas is another aspect of the wildland fire management. Figure 2 represents a synthesis of the components of the problem.

It would be interesting to associate the fires of the wildland-urban interface (also the threatened goods), which represent the highest ignition, with a large fire danger estimation. These two kinds of danger seem to be independant, but are acting on one other. This foreshadows what should be a decision support system integrating the different kinds of danger.

From A Scientific Point Of View

From a physic point of view, a conflagration is defined by the amount of released energy and spread. When crown fires become very large and intense and spread quickly, fire managers rename them conflagrations, which are large destructive fires with moving fronts and high rates of spread. Conflagrations often throw embers a long distance ahead of themselves. This phenomenon is called spotting.

Basically, we distinguish between large fire and conflagration. We can have only a large fire if the product energy*speed is not enough. On the contrary, there is the possibility that a conflagration occurs even if it is not a large fire in terms of the area burnt. A starting fire can quickly turn into a conflagration.

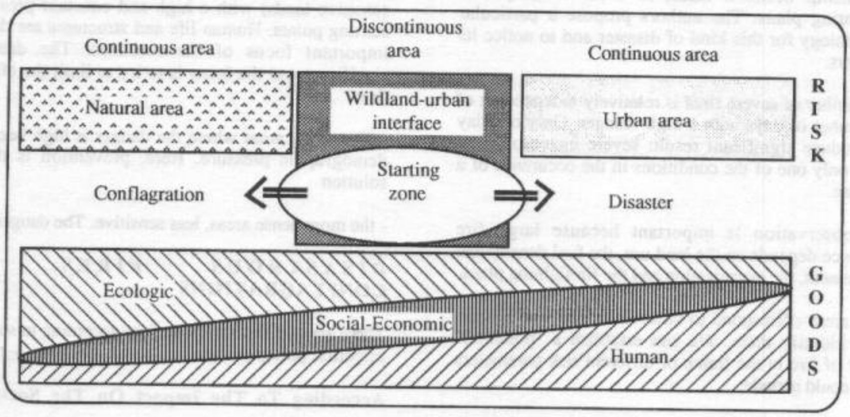

figure 2: Disaster and conflagration

We have two poins of view on the problem. One is considerating the operational aspect and the fire is defined by the area burned and the damage caused by the fires. The other approaches the fire by its energy aspect.

CONCLUSION

In the French mediterranean area, the characteristics of wildland fire require to have a revison of wildland fire management. Managers and firefighters, responsible for prevention and firefighting have to take into acount the changes which we have noticed above, i.e, both the decrease of small and medium size fires and the growth of the large fires.

In this paper, we indicate this evolution and show a new framework for evaluating a large fire, associating an other component: the fires of wildland-urban interface which represent most of the starting points and concentrate human life and structures. The integration of this framework within a large fire danger estimation, could be an interesting way for a better wildland fire management, both for managers and researchers, willing to approach the reality.

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TIEMEC '95

Natural Hazards (Avalanches and Landslides)

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MERGING DATA ANALYSIS AND SYMBOLIC CALCULATION INTO A DIAGNOSTIC SYSTEM FOR NATURAL HAZARDS

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KEYWORDS : diagnostic system, natural hazard, hybrid model.

ABSTRACT

Much theoretical work has been done in the building of diagnostic systems to protect oneself from natural calamities. The two classical approaches to solve this typical non-algorithmic problem are case-based reasoning and knowledge-based reasoning. Each of these approaches has already given good results, but also shown its limitations. Following the idea that they may be synergetic, a research project with the goal of merging a data analysis system and an expert system into one single "hybrid system" was initialised at the Swiss Federal Institute for Snow and Avalanche Research (SFISAR) in 1991.

The first step of the project consisted in designing the theoretical model, by defining the different calculation processes and the resolution sequence. This begins with the determination by rules of the parameters of a k-nearest cases selection procedure. It proceeds with the extraction of the nearest solved cases from the database and concludes with an inference session giving the diagnosis from the data of the case to be analysed and the data of the nearest solved cases.

The second step of the project involved the implementation of an operational computer application usable in real time by practitioners. This tool is composed of a file manager including data control procedures on the one hand, and the diagnostic system on the other hand. It has been designed to run on a PC to be easily used in actual conditions and without high costs. An evaluative phase for the estimation of diverse natural hazards is now in process.

At the present time, the next step consists in adding optimized machine learning procedures to the model in the hope of giving it the capability of improving its performance by itself.

INTRODUCTION

Forecasting an event (an avalanche, a wildfire, etc.) is always the first problem of natural hazard prevention.

Prediction is often based on previous experience, and these experiences are available to us in many different ways. The simplest form is a recording of measured values, observed facts and, of course, of the pertinent event. From them if we are lucky or a genius we may find a close relationship between these values and the event and call it a physical law (example: the hydrogen absorption lines found by Balmer, the Balmer series). In order to find such relations among variables, of which one is normally called the event, mathematical tools are available in statistical software packages. Assuming normal (Gaussian) distributions of the variables all goes well with classical parametric statistics and we may calculate correlations, find clusters and factors. From these results we may infer the chance of the occurrence of the event, given the values of the relevant variables. The advantage of such methods is the ease with which we can perform the calculations for new cases, which is a consequence of the mathematical formulation of the distributions and the very limited number of parameters of the statistic (mean value, standard deviation). It is even possible to forecast an event that has never occured so far.

If there is a good number of observations available we may use non-parametric statistics which is essentially a case-based reasoning : if all the circumstances causing the event are the same as already experienced at least once in the past, then the event must be the same as in the past. The logical issue of this idea leads to the method called "nearest neigbour" or "k-nearest neighbours". The advantage is : no assumption about distributions and their parameters concerning the variables. Both methods mentioned above need variables, measured values and observed facts, on which depends the event. However this is not the only way we store our experience. There are rules, knowledge. These ideas lead to expert systems and artifical intelligence models. Data of the past is "compiled", keeping the essential (for the expert). Details will be lost (such as date of occurrence) : even worse the essential may get lost if it is not recognized by the expert. Therefore the experience of more than one expert is needed.

As a simple conclusion we may say : the first two models need data of the past, the last mentioned models need rules and knowledge of the present (although having its roots in the past).

The usual question is what model is the best ? One answer is "try all of them" (Weiss et al, p.145-176). In fact, each resolution method has its own advantages and limits. According to the idea that they may be synergetic, we have decided to merge two different models into one single system. One uses the nearest neighbours method whereas the other one exploits classical artificial intelligence techniques. In fact, this merging simulates a human being reasoning using theoretical knowledge and practical experience at the same time. In every day life, such reasoning is very frequent and very efficient. One of the best illustration is given by a child learning to read : he "decodes" new or unusual words with the help of phonetic rules whereas he directly recognizes the words he is used to see. The diagnostic model we present here is designed to work like this child. Thus, two different aspects have been treated : data analysis and symbolic calculation.

The first section of this paper presents the theoretical approach to the problem and the second one describes one practical application. The conclusion explores the different fields of utilization and the development perspectives.

1. THEORETICAL MODEL

Data Analysis

In the nearest neighbours model we need some prescriptions of how to find them. There is the problem of the relevant variables. In most practical situations we have to adapt the method to available data. Next problem is the strength of influence of the variables on the event. For instance, it is well known that the amount of fresh snow has a great effect on the occurrence of avalanches. Other variables have minor influence. Therefore a weighting matrix is introduced. There are statistical means for calculating the weights, one of which is very elegant since it leads at the same time to the definition of the statistical Mahalanobis distance (McClung, 1994). However this excludes the introducing of expert knowledge. Experts put different weights on the variables, depending on their value. Mathematically speaking, they use nonlinear relations between variables and event. In order to account for that, different weighting matrices will be used. In our present model, we can consider different kinds of situations and attribute to each of them a specific weighting matrix. But we are still faced with the problem of calculating the distance needed to select the nearest neighbours of the case to be analysed. There are several definitions : the Mahalanobis distance mentioned above, the Euclidian distance commonly known and others. Using the Euclidian distance, the components are assumed to be orthogonal, that is the variables describing cases should be independent. Then the distance between two vectors in the space of cases is :

$$d(x_i, x_j) = \sqrt{\sum_{k=1}^{n} [\alpha_k . \beta_k . (x_{i_k} - x_{j_k})]^2}$$

with :

x_i, x_j : vectors of space
α : weighting factor (real)
β : normalization factor (real)
n: dimension of space

We could introduce a weighting factor $\alpha'=\alpha.\beta$. However α and β have a different meaning : α is considered the true weight, whereas β is chosen such that the range of the numerical values is about the same for each variable, that is each one is given the same weight for a start. Thus the expert's weight (α) directly shows the importance he attributes to a variable.

Symbolic Calculation

The inference phase simulates deductive reasoning. We have chosen to represent the experts' knowledge with the help of production rules because it seems easier to formulate their experience according to this formalism. But natural hazards are dependent on such complex phenomena that many of the rules used by experts are empirical and uncertain. Moreover, they have sometimes to work with doubtful values coming from field measurements. So we had to take into account these uncertainties when modeling reasoning.

The first question is : how to represent uncertain knowledge ? For our problem we can admit that the facts we manipulate are observable and that the notion of occurrence frequency has a meaning. With this assumption the mathematical theory of probabilities brings answers : we have chosen to qualify each fact used by the model by a probability coefficient. Thus, for the system each fact is an expression the formalism of which is :

fact = record
v : real (value)
p : real Î [0,1] (probability coefficient)

This allows to deal with uncertain measurements or deductions. But there is still another kind of uncertainty. Experts often make statements such as : "if the value of... is *around*... then the value of... *may be*...". This indicates that they make inferences from uncertain facts by using uncertain rules ! To represent this process we have also quantified the likelihood of each rule by a probability coefficient. This represents the supposed frequency of validity of the rule.

In order to simulate the reasoning more easily, we have adhered to one condition when writing knowledge basis : when several facts are needed to trigger a rule, they must be independent. According to this prescription, the process for producing uncertain deductions is :

$$F1_{(P1)} \xRightarrow{R_{(P)}} F2_{(P1.P)}$$

$$F1_{(P1)} \wedge F2_{(P2)} \xRightarrow{R_{(P)}} F3_{(P1.P2.P)}$$

$$F1_{(P1)} \vee F2_{(P2)} \xRightarrow{R_{(P)}} F3_{(P.(P1+P2-P1.P2)}$$

with :

Fi : fact
Pi : probability of fact i
R : rule
P : likelihood of R

Generally we try to decompose knowledge as much as possible in order to write simple rules. For example, if we have :

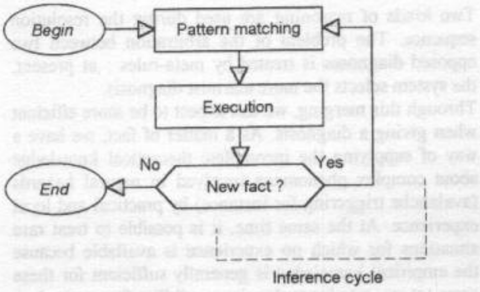
$$A \vee (B \wedge C) \Rightarrow D$$

then we write :

$$B \wedge C \Rightarrow E$$
$$A \vee E \Rightarrow D$$

Using fact E is not only simplification for calculation. It also facilitates releases of knowledge bases. The latter one may consist of thousands of facts and rules, and the inference engine has to exploit all these fragments of knowledge (got from experts with the help of Protocol Analysis method) to build the diagnosis. We have chosen to make it work by forward chaining until the knowledge basis is stable.

The principal process is :



The session stops when the inference engine cannot produce new facts.

The main characteristics of our inference engine are : forward chaining (only), order 0+, and irrevocable strategy (no backtracking).

Merging Data Analysis And Symbolic Calculation

In the course of a resolution sequence, the model uses rules (that is to say the knowledge basis) to drive the data analysis procedure and then the results of the latter to complete the knowledge basis. This is the reason why we speak about "merging". The following table gives an overview of the process by showing the input and output of each main step of the resolution sequence.

Step	Input / Process / Output
1	Input **-Data of the problem** -Meta-rules Process Symbolic calculation Output Data analysis parameters (weighting coefficients)
2	Input -Data of the problem -Output Step 1 -Database (solved cases) Process Data analysis (k-NN method) Output Solutions for analogous problems
3	Input -Data of the problem -Output Step 2 -Expert diagnostic rules Process Symbolic calculation Output **Solution of the problem**

Two kinds of reasoning are used during the resolution sequence. The problem of the arbitration between two opposed diagnoses is treated by meta-rules : at present, the system selects the more alarmist diagnosis.

Through this merging, we can expect to be more efficient when giving a diagnosis. As a matter of fact, we have a way of supplying the incomplete theoretical knowledge about complex phenomena involved in natural hazards (avalanche triggering for instance) by practical and local experience. At the same time, it is possible to treat rare situations for which no experience is available because the empirical knowledge is generally sufficient for these cases (at any rate for avalanche or wildfire forecasting).

2. PRACTICAL APPLICATION

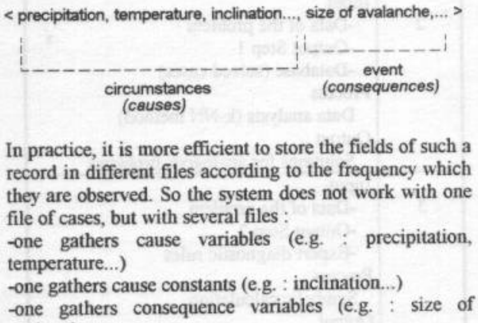
The model has been implemented so as to be widely tested in actual situations. The software is called NXLOG because it uses principles and some functions from two systems previously designed for avalanche forecasting : NXD (Buser, 1989) and AVALOG (Bolognesi, 1993). It is easily configurable for different similar diagnostic problems. So we may use it to help in forecasting various natural hasards. Of course this is possible only if strong expert knowledge and numerous actual cases described by relevant variables are available.

The system is designed to run on a personal computer. It proposes to the user two functions : data management and events forecasting.

Data Management

The system permits the storing of cases and other data required. Let us remember that a "case" should be a record of data reporting or describing the event (an avalanche, a fire...) as well as its circumstances : a "case" associates the event with its assumed causes.

Example :



In practice, it is more efficient to store the fields of such a record in different files according to the frequency which they are observed. So the system does not work with one file of cases, but with several files :

-one gathers cause variables (e.g. : precipitation, temperature...)

-one gathers cause constants (e.g. : inclination...)

-one gathers consequence variables (e.g. : size of avalanche...)

As each record of these files has at least one common identifier field (date and location of the observation in our application) there is no problem in reconstituting the cases.

When using the data of the past to build a diagnosis with the k-nearest neighbours method, one assumes that these data are quite reliable. But we know that many mistakes may be made when entering data in a computer... So we have implemented many data checks which inform the user if the entry is outside its possible range or outside its usual range. These different ranges are parameters : this makes the system more adaptable.

Events Forecasting

NXLOG gives the user the probability of occurrence of the event to be forecast. As natural hazards are generally spatial events depending on geographical parameters, it is important to have different diagnoses according to the different locations involved. The system is able to apply the model to all the different locations requiring control. For instance, in quantifying avalanche hazards, the system determines the probability of an avalanche for each described slope of the considered mountain area.

As additional informations, the system also displays some intermediate results like the 3 nearest cases (circumstances and events).

CONCLUSION

Even if our researches have theoretical aspects, our ultimate goal is to develop diagnostic systems usable in practice. Therefore, we have established many contacts between the Institute and the practitioners in order to design the products needed and to test them in actual situations. At present more than 15 European safety services work successfully with our systems for avalanche hazard diagnosis.

Although the model has been developed for avalanche forecasting, it may have become evident to the reader that it should work for any event which depends on measurable and observable facts. Thus applying the model for the prediction of forest fires was so encouraging that a project has been initiated in cooperation with a group working on fire prevention in the southern part of Switzerland.

At the present time we are working towards integrating machine learning procedures in the diagnostic process. This may be a way of increasing the power of the system. This new research project is just now beginning at SFISAR with the cooperation of the Artificial Intelligence Laboratory of the Swiss Federal Institute of Technology at Lausanne. We hope for first results before 1997.

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BIOGRAPHIES

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Graduate from the University of Sciences of Grenoble, France (doctor's degree, June 1991 and diploma of "Research Management", June 1994). Has worked as avalanche forecaster in the safety service of a large ski resort. Now in the staff of the SFISAR, leading researches about Machine Learning in order to try to improve decision support systems for avalanche control.

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SOME ASPECTS OF COMPUTER AIDED DECISION MAKING FOR THE CRISIS MANAGEMENT OF UNSTABLE SLOPES

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KEYWORDS: crisis management, object oriented database, GIS, ground model.

ABSTRACT

We present here the developments in our risk management research; software tools based on object oriented techniques, an image and graphics based man-machine interface, a new algorithm which allows the quick construction of a GIS, strong links with analysis software with the possibility of using fuzzy logic reasoning. The case of the threatening landslide at Sechilienne (Isere, France), studied using these tools, is briefly presented. We will show that its management is facilitated through the use of networks as in the WASSS project approach (Faure *et al* 1995a).

RESUME

Nous presentons ici l'evolution de nos recherches en matiere de gestion du risque. Les outils informatiques mis au point s'appuyent sur les techniques orientée objets, les interface hommes machine comprenant l'image et le graphisme, un nouvel algorithme permettant de construire rapidement un SIG, les liaisons fortes avec des logiciels de calcul et des possibilités de raisonnement en logique floue. Le cas de Sechilienne traité avec ces outils est brievement presenté et nous montrons que sa gestion est facilitée par la mise en reseau dans la philosophie du projet WASSS (Faure *et al* 1995a).

INTRODUCTION

At the TIEMEC '93 symposium in Arlington we presented a paper (Faure *et al* 1993) which described the basis of an array of computer tools that improve risk management. This article is the follow-up to that paper, presenting the research and applications developed since to provide the crisis manager with quick easy to use tools.

The purpose of these tools is to provide the decision makers, as rapidly as possible, with the necessary decision making elements, in both surveillance and crisis period, while, at the same time, trying to evaluate the consequences of that decision. The computer hardware and software choices result in optimal product maintenance and portability, without forgetting the networks aspect, which is ever increasingly necessary for large area management.

AN OBJECT ORIENTED DATABASE FOR REASONING AND ANALOGICAL REASONING

In this section, the choices made for data management are explained. We have already described what kind of help an engineer should obtain with our crisis management system. The amount of data needed to properly identify the context of an impending landslide is very large and varied. In fact, the nature of information stored about an existing slope is both quantitative and qualitative: requiring simultaneous management of geotechnical, mechanical, hydraulic, sociological, historical and infrastructural data.

This data must be well organized, structured and classified in order to facilitate information searches and to answer an engineer's request. We will see here, that such information can be represented in several ways through *graphic user interfaces* (GUI). It would also be convenient if data extracted from a database did not require organization and restructuring in memory before presentation.

However, the system should be able to simulate disaster senarios in order to study crisis situations: computation and reasoning codes are applyed to some data to propose remedial works. Those codes place constraints on the organization of the data. Each program needs to retrieve the data in a particular fashion: for example, slope stability processing requires geotechnical and hydraulic characteristics. The reasoning component can require every type of information including results of data processing. The best way to take care of these ideas consists of structuring the data with complex objects. The notion of object models provides many concepts which are useful for our modular system; the principles of abstraction, classification, modularity and *point of view* can be easily implemented with object-oriented programming. Thinking of

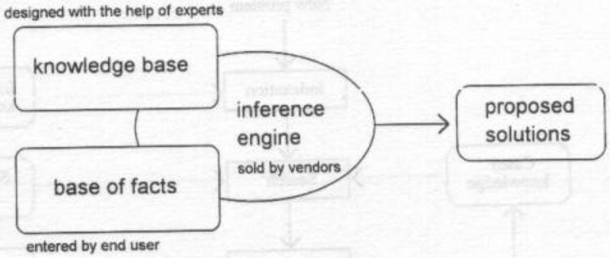

Fig.1: *A flowchart depicting the classic expert system.*

data as complex objects, or, in other words, object-oriented design allows to make the most of the expressive power of object-oriented programming languages. Also, It allows software components to be re-used and to increase system reliability against modifications (Booch 1992).

The whole system handles data as complex objects, especially at the database level. We decide to use an object database management system to create an object schema (Gardarin *et al* 1991) – which is a description of a specific object database, including classes, attributes, methods and links between classes – well adapted to the subsequent processing and also to to reasoning. For example, a slide stability computing program answers a request and retrieves from the objects database the desired objects to process. The use of a newly available *objects server* (ILOG 1994) ensures internal object model coherence (inter-object relations, derived attributes, origin and context functions) and external coherence. In addition, the object database manages simultaneous access to data, data integrity, security and persistency.

Since these objects model the situation of a slope, including geographical and mechanical information, they can be used as a base of facts for an expert system. Reasoning can thus be launched to deduce conclusions about the risk or about remedial solutions, with the empirical approach of an expert. The conclusion comes from a knowledge base applied to a base of facts (the application of the base of facts is performed by an inference engine), cf. Fig.1.

The object database also stores information about remedial solutions which have been adopted for past landslides. This data represents known cases of solved problems in slope stability. The object database has to keep useful information for an analogical reasoning, or more especially for a case-based reasoning. It consists of referring to the most similar existing and solved cases to find a solution to a new problem. Fig.2 presents a potential model to understand how this reasoning process works. This approach requires a large data base which the WASSS project attempts to provide.

As a first step, case-based reasoning can be used as a simple help for slope stability experts. The system just proposes judiciously repaired landslide cases and lets engineers think about the best solution they should adopt.

THE NEED FOR FUZZY LOGIC

One of the characteristics of the problems in soil mechanics is that the data is imprecise. The reasons for this are numerous. Firstly, the scale of the problems is far larger than the soil sample or human scale. The extent of the mass of soil can reach hundreds of metres. Secondly, soil, the material being studied, is not directly accessible and mainly hidden from human sight. Furthermore, knowledge of the great mass of soil is only punctual since it comes from a limited number of drill holes.

All this makes the knowledge of the geometry (the different layers) very imprecise, not to mention the geotechnical characteristics, as soil is highly heterogeneous. The question of groundwater is even more complex. Not only is the position of the water table difficult to determine, but the flow net varies with precipitation and the seasons.

The design of an expert system for soil mechanics has to take the imprecision into account. The problem is that most inference engines deal only with precise data. The vast majority of them consider symbols in their inferences. So in soil mechanics, the symbol will be vague, with lots of "small", "large", "medium", "high", etc.

The question is; what does "small" mean? This notion is not common to all experts, and it is not easily understood by those who use the expert system. And since "small" and other notions are not clearly defined, the reasoning (that is the rules) will be highly imprecise and, as consequence, useless. It is one of the reasons why it is apparently so difficult to design an expert system for soil mechanics.

Fuzzy logic has been introduced to solve the problem by quantifying the imprecision. Instead of being qualified by a symbol, a variable is known by a distribution of possibility. This can only be applied to numeric variables, but they are the ones that are affected by imprecision. For a variable, each value is given a possibility coefficient. If the coefficient is equal to

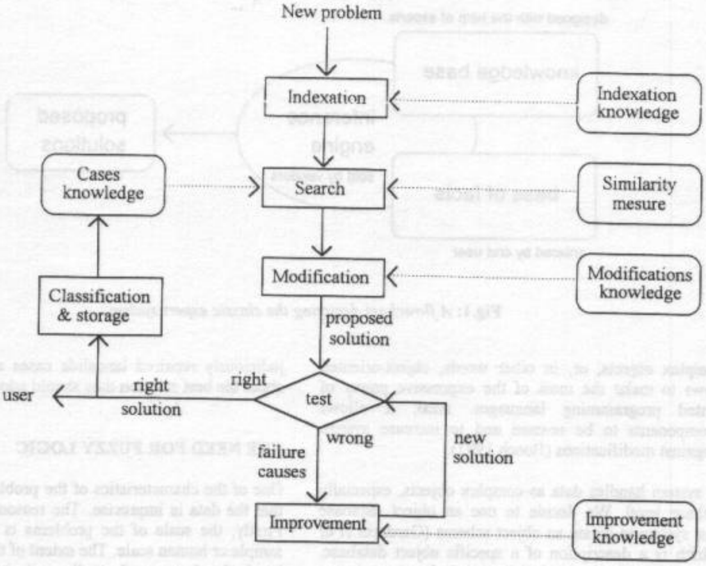

Fig.2: *A flowchart depicting the analogical reasoning process.*

one, it is absolutely possible the variable has this value. On the opposite, if the coefficient if equal to zero, it is absolutely impossible the variable has the value. Thus, each value gets a coefficient between zero and one. An infinite number of values can be absolutely possible or absolutely impossible (this is one of the great differences with the probabilities).

With this formulation, it is possible to represent the notion of "small" or "large" with precision, while they are imprecise. And they can be used to write rules. Roughly speaking, a fuzzy rule is something like:

if variable1 is more or less between value1 and value2

then variable2 is more or less between value3 and value4"

(**Note:** this is only an example to help understand fuzzy logic, this ***is not*** fuzzy logic).

The real representation of variable1 being a distribution of possibility too, fuzzy inferences provide a mean to determine the distribution of possibility of variable2 given the distribution of possibility of the rule and of variable1.

With fuzzy logic, the design of an expert system in soil mechanics should be easier. As a part of the XPENT project, rules are being *fuzzified* to verify the feasibility of a fuzzy expert system for slope stability.

SPATIAL POSITION OF THE FACTS

It is necessary when building an Object Oriented Database for analogical reasoning on slide classification to have an easy to use interface for entering and consulting the data. It must provide an open structure so that the user entering his information doesn't have to consider their constituants. Of course, the less he has to do, the better and the faster it is. For this, we have choosen to provide a graphical interface based on the usual widgets (radio button, etc.) following international propositions (based on the World Landslide Inventory works (Cruden 1991)) on the way slides should be described. This allows the classical data common to each case to be entered quickly. For more specific information, such as images, maps, texts, illustrations, or everything else, we just make a link between the database and the file containing the information. When consulting the database, we suggest to associate a viewer for each type of non-usual object, which allows multi-platform use and independance of the information.

Our interface is also based on a network layer, which allows multiple users working at the same time on the database. The integrity problems have been solved by using pre-build products to manage the system (ILOG systems: Views & Server).

To structure geographical information, we have chosen to use a map as the background. This way, we get information on a region by clicking on it. We have at the same time the ability to access any slide presented on the map. When entering new information, we process it in the same way: firstly, we delimit with the mouse the region of interest, and then we have access to the entry interface. This mecanism is of benefit when considering interaction between different cases, because it facilitates the retrieval of geographical information.

LINKS WITH COMPUTATIONAL CODES

Computational codes are an indispensable component of the software tools required by the engineer. Such codes can perform quickly (using numerical tools such as the finite element method) otherwise laborious scientific calculations, thus furnishing the engineer with important information such as safety factors, pore pressures, etc.. In terms of risk management, they must be linked with the other tools in order to provide maximum efficiency. That is, they must be accessible via a user friendly interface that, in addition, allows access to the necessary data from a GIS, or an expert system, etc..
Even though computational codes are, in general, written to solve very specific problems, (e.g. the safety factor of a sliding slope or the pore pressures resulting from unsaturated flow as cited above) their output may be required as input by various other programs that perform completely different tasks. Consequently, the results can often be so important they can modify an entire project. Thus, it is necessary for every computational code to be validated by an expert in the field. Once the validation is performed, any change must be checked. Therefore, care must be taken to ensure that the results can be used by very different programs without having to adapt the code to individual needs. (Adaptation in this context means to change in a program that has been validated; a change may bring into question the integrity of the results.) Thus, once a computational code has been validated it must be separated from the rest of the programs, treating it as a completed module or "black box" and ensuring that it is not being changed constantly.

The modular approach to developing calculation codes also has the practical advantage that it facilitates development by a team. Each module is written independently, and consequently, where a team member disappears (as in colleges, when a student has finished his studies) the work is not lost, as all that is required by subsequent developers is the input and output format.

If the computational code is a separate module, the only point where attention should be focused is the interface: what to put in and how to retrieve results. From the design standpoint, the problem is to know how to transmit information. The answer depends on the software environment. Since that environment is evolving rapidly, the method has to change with it.

The solution that was decided upon at ENTPE was dialogue using files. Any program that needed a computational code created a file with the information the code needed (a slope, boundary conditions, etc.) then it launched the code. The code read data from the file (whose name was standard), computed and created a result file. At the end of the execution, the main program read the result file (with a standard name again). This solution worked perfectly well until Windows was used.

The exchange of file works if the main program knows when the code has finished. With Windows, this it is difficult to know because Windows is a pseudo-multitasking environment. Because we had decided to use programs that worked with files, we were forced to find a solution. However, currently, this approach within the Windows environment requires an advanced knowledge in Windows programming and is

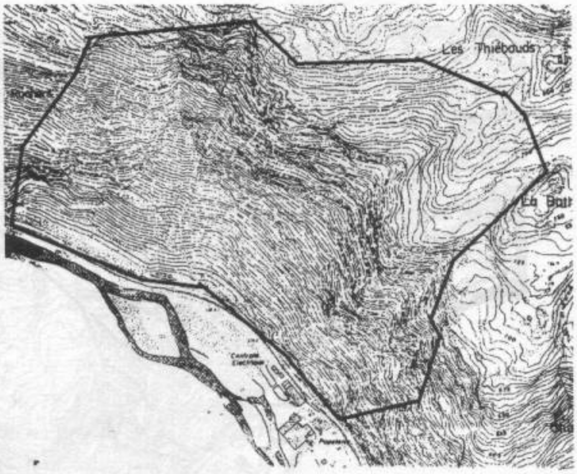

Fig.3: *A map of the area around the landslide at Sechilienne* (Isere, France).

consequently a stumbling block to heavy development.

In the future, the problem will be solved thanks the object technology. An object being an independent module, it satisfies all requirements. This is one of the reasons why all development at ENTPE is now done in C++. This object technology has been used in the design of Nixes & Trolls Windows, a program that computes the safety factor of slopes. All information is provided to the code by a GUI via objects. The same method has been used with PIR3D, a rockfall simulator (Faure *et al* 1995b).

RAPID GROUND MODELLING FOR SLOPE STABILITY ANALYSIS.

Like all information pertinent to an impending landslide, the geographical and topographical data is vast (Buisson *et al* 1993 & 1994). In the context of an object oriented expert system for landslide management such information is stored as a set of objects (e.g. buildings, roads and zones) placed punctually in space (i.e. **x,y,z** co-ordinates) but the actual surface may not be stored. Where it is stored it is either stored as:

1. A set of points on a regular grid,
2. A set of contours as read from a map.

The former, though possibly detailed (France has been covered by a 5m grid) reveals little about more complex features such as ridges, hill crests and troughs. The latter, though visually meaningful, is difficult to interpret automatically in computer codes. Added to this is the fact that both types of representation involve a lot of data.

For the engineer in the field, who wishes to perform a quick slope stability or groundwater flow calculation for a given site, the step from grid or map to the slope profile necessary for such calculations is vast. In the case of a crisis, the necessity for a quick method to achieve this step is of paramount importance. In this section we propose a quick method that avails of the facility of computer graphics interfaces and a new constrained mesh generation algorithm (Robinson 1995).

The rapid ground modelling (R.G.M.) method presented here is based on the use of line contoured maps. These maps can be stored in the computer as bitmaps (in the case of an object oriented database) or can be easily scanned into the system in the case of a crisis. Fig.3 shows such a map of the area around the landslide at Sechilienne (Isere, France) after scanning. It is used as the background for the graphics interface proposed here.

The thick black line represents the perimeter of a hypothetical area of interest. The important point to note at this stage is that the polygon has been entered with the mouse using visual criteria. (Although we sometimes tend to develop fully automatic systems, the human brain is sometimes the most efficient processor.) The **x,y** co-ordinates are generated automatically from the mouse cursor position and the elevation can be simultaneously typed in.

The next step is the innovation proposed here. The user visually discerns important features that describe the surface such as hill crests, ridges and troughs as shown in Fig.4. The idea here is that this process results in an adequate description (for slope stability calculations, etc.) of the surface with a minimum number of points. If these points were entered punctually there would be no guarantee that they would result in the representation of the ridges, etc., after standard triangulation. However, the use of a constrained mesh generation algorithm (Robinson 1995) ensures that the mesh conforms with the features. Fig.5 shows the mesh generated over the 81 points entered.

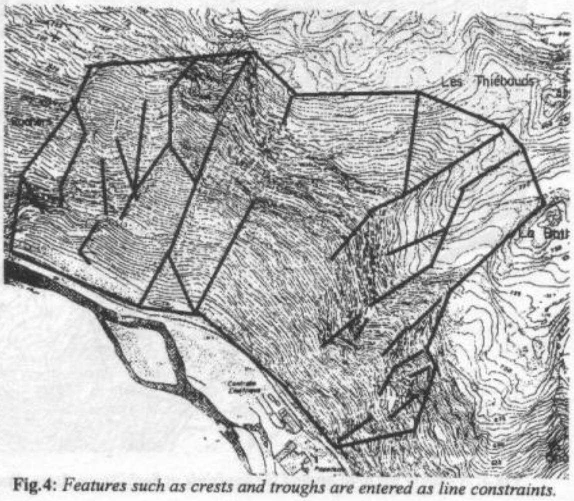

Fig.4: *Features such as crests and troughs are entered as line constraints.*

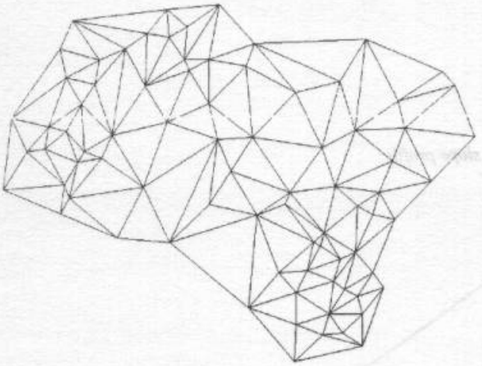

Fig.5: *A mesh that conforms to the features is easily generated.*

At this stage a ground model for the zone of interest has been generated. Fig.6 shows the **3D** representation of the surface (with shading from a vertical light source). The surface can now be "sliced" to provide a vertical profile in any direction as seen in Fig.7 & 8. Thus, the profiles needed as the geometrical data for many slope calculations are quickly and easily generated.

This system also facilitates the generation of surface parameter data necessary for 3D programs such as PIR3D or flood simulation tools. A zone defining a forest, grass or soft soil area can be entered using the same graphics interface as for the ground model polygon. Subsequently, any triangle in that zone is allocated the corresponding surface parameter value.

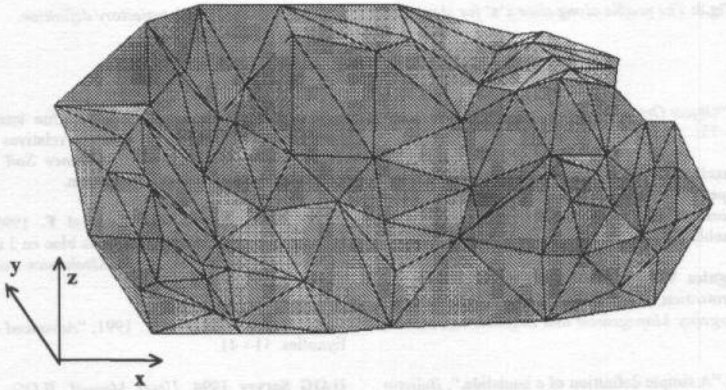

Fig.6: *A 3D image of the ground model.*

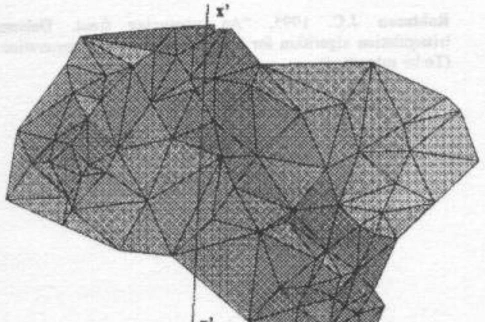

Fig.7: *The ground model can be sliced to produce a profile.*

CONCLUSION

The real benefit of all these new risk management tools is clear if they are quickly and easily available to all. The solution to this is the use of computer networks. In the WASSS project (Faure *et al* 1995a) we are developing, using Internet, a wide array of such tools that will soon be used by other universities.

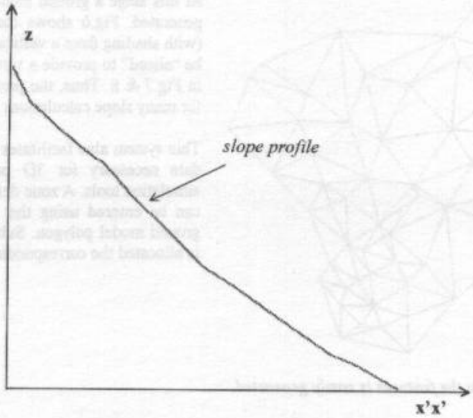

Fig.8: *The profile along slice* **x'x'** *for slope stability calclations or 2D block trajectory definition.*

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DECISION SUPPORT SYSTEMS FOR THE PREVENTION OF SLOPE RELATED NATURAL HAZARDS: A PERSONAL VIEW ON THE FRENCH SITUATION

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KEYWORDS : prevention, hazard mapping, modelling, geographical information systems, knowledge bases.

ABSTRACT

Recent progress in computer science has allowed for the development of new decision support systems for the prevention of some slope-related natural hazards. This paper will give a survey of the present situation, the areas of development, and the research trends which can be observed in France. In order to be factual, several examples of operational tools or systems currently under development are quoted or described.

Different natural hazards can occur on the slopes of high mountains or in hilly areas i.e. snow avalanches, landslides or rock falls. The basic ideas for the prevention of these hazards will be presented. This paper will then focus on different solutions used in France to prevent these hazards. The emphasis will be on different kinds of mapping and the problems of building regulations and equipment protection will also be discussed.

In this context, a decision support system can take advantage of different types of information and knowledge which the author will address. A classification of simulation models and analysis methods will also be proposed and the issue of available data will be discussed. Attention will be paid to the accurate topographical and field data which are presently collected in France.

Finally, the new capabilities of software tools will be described. Their graphic interfaces are highly interactive and user-friendly while their architecture enables the different methods or models to be integrated.

INTRODUCTION

Decision support systems are developing in many application areas. Since the middle of the 1980's in the field of natural hazards prevention, a large number of systems have appeared in France. Looking at the present, the 1990's what is the current state of development and use of these systems ?

A few authors have tried to assess the situation. For instance, Asté and Badji (1994) describing the "promises of Artificial Intelligence" and surveying a few applications based on this approach, note that present results are *rather negative* and suggest so-called *"new ways"* to develop decision support systems i.e. GIS, multi- and hyper-media, object-oriented programs.

This author thinks that the situation is probably more complex and that and in order to produce a better analysis to make better decisions in future developments, we need to look at the context of the natural hazards accurately, and at the adaptation of the means to develop the actual application's goals. As a matter of fact, if funding and time are critical parameters, the choice of a tool and the required input data is not a question of fashion but a question of necessity.

This paper presents a French point of view on this topic. Since concepts used in this paper are French, they might be different from those used in other countries because of differences in the laws, the language and the culture.

SLOPE RELATED NATURAL HAZARDS

Which Phenomena ?

In France, the natural hazards related to slope are the most dangerous, based upon the number of casualties. This paper deals mainly with snow avalanches, slope instabilities, rock falls and rock avalanches. These phenomena occur generally in high mountains or in hilly areas. Torrents which also create actual threats in mountain valleys are not taken into account in this paper.

The common property of the hazards studied in this paper is that they are defined on a localized geographic area. That is not the case of other hazards such as forest fires (which are very difficult to define geographically), earthquakes (which cover large areas with undefined boundaries), and river or torrent floods which can cover a very large area. As a result, for slope related hazard prevention, mapping appears as an interesting possibility. Moreover, these phenomena may be described through the spatial distribution of their physical properties (density, velocity, pressure…).

Which Frequency or Which Probability ?

A *hazard* is defined through the description of a phenomenon and an estimation of its frequency. This frequency can be related to the occurrence of the phenomenon or to the properties of the phenomenon. For instance, we can speak about an avalanche path on which avalanches naturally happen twice a year. We can also speak about the probability that a building will be hit by a falling rock on a particular slope.

Which Risk ?

The *risk* is defined by the combination of the hazard, human activity and the presence of property in the threatened area. There can be an avalanche hazard without threat to people or property. We can say, for the same hazard, that the risk is not the same if there is a school in the path of the hazard compared to a power line in the path. Clearly, the school, if occupied is a greater risk.

In the case of slope-related hazards, two kinds of accidents can occur. On the one hand, alpine, mountain or off-track skiers can be victims of avalanches or rock falls which take place in *wild areas*. On the other hand, if *a building or if equipment* (ski-slopes, ski-lifts, roads, railways, power lines…) are hit, damaged or destroyed by avalanches people can be hurt or killed. This paper focuses on the second type of accidents and the related risk. As a matter of fact, in order to prevent the first type of accident, the only solution is to train people and to provide timely warnings adapted to large areas.

PREVENTION

Beside "hazard mapping" which will be described later in this paper, other prevention methods can be used to prevent accidents. They can be classified according to two points of view which are briefly presented here. This chapter is not a "prevention system directory". It aims only to present an idea for the general context of decision making in the field of natural hazards (Rapin, 1991a). Basically, we use two criteria to classify the different prevention methods, but many others might be used.

Active and Passive Prevention

The purpose of the *active prevention* is to act *directly* on the phenomenon in order to prevent it from occurring, to reduce its magnitude or its frequency or to choose the time of its occurrence. Indeed, the active prevention must intervene forcefully in the phenomenon.

On the other hand, the aim of the *passive prevention* is to modify or shelter the persons or the property needing protection. Some kinds of passive prevention may only minimally interrupt the phenomenon.

Permanent and Temporary Prevention

A *permanent prevention* is supposed to be effective without concern for when the threatening phenomenon occurs. This kind of prevention is permanent.

A *temporary prevention* needs to be implemented according to the current level of hazard and it requires a time-dependant analysis of the danger.

Examples

Snow Cover Retaining Structures

In order to prevent avalanches from being released, different kinds of retaining structures have been developed: snow-bridges, snow-racks or snow-nets. Their function is not to stop an already released avalanche but to prevent the initial fracture and slide which can trigger an avalanche. As a result they are said to create a permanent protection. This protection is permanent while the snow cover is not too deep and the structures are maintained.

Landslides Monitoring

In the case of landslides which threaten a road or some structure, a monitoring system can be implemented. It may consist of a set of sensors connected to an automatic or manual warning system. Regular surveying measurements could be used as an alternate method. If road closure or evacuation is necessary, it must be planned. This is considered a passive or temporary protection.

Avalanche Blasting

By using explosives or gas exploders, trained personnel can trigger snow avalanches. This is a convenient method to release an avalanche which threatens a road. Naturally, the road must be closed. This is also a useful method to reduce the magnitude of the avalanches on a particular path. With regular blasting during heavy snowfall, the released avalanches will generally be small and no heavy snow cover will accumulate on the starting zone. This requires a good real-time analysis of the behavior of the starting zone.

Rock Falls Dams

Facing a rock fall threat, a passive prevention method may be using a dam in order to reduce the probability that a rock would smash into a structure or land on a road. As long as the dam is not destroyed or the size or the number of rocks increases due to other conditions, this relative protection is permanent and efficient.

Large Area Forecasting

Large area forecasting is very important in the case of snow avalanches or rock falls. It is likely that in peculiar weather conditions (heavy snowfalls, thaw periods), the risk level might be high on sites on the whole mountain range. Forecasting is then used in order to write hazard warnings which do not deal with a particular site but with the whole mountain range. As already explained, this paper does not take into account this kind of decision support. Meanwhile, these warnings may be used by road services or ski patrols when they try to monitor the current hazard following a particular path. This local hazard forecasting which is becoming more and more important will be briefly discussed.

Choosing a Protection System

To choose a protection system, the engineer must have an accurate description of the phenomenon and its properties, an assessment of the frequency or probability, and an analysis of the actual risk, taking into account the nature of the structures and property in the path of the hazard. Following are some examples. The snow height distribution on the starting zone must be accurately known before implementing any retaining structures. The probability distribution of the run-out distance of falling rocks is key information in designing a dam. Finally, avalanche blasting cannot be thought of as a solution above inhabited areas.

"HAZARD MAPPING"

Beside the protection solutions which have just been presented, "hazard mapping" is an alternate and complementary approach. The purpose of this paper is not to give an advanced analysis on this important and complex topic. As explained in the introduction, it can be convenient to describe one of the circumstances in which decision support systems may be used.

"Hazard mapping" could not be analyzed without taking into account several points of view such as the scale, the legal value, the nature of the represented phenomena and the source or the content of the displayed information… In this paper, natural hazard maps are classified according to only two important points of view : the legal one and the content one.

Warning and Regulation Maps

There is a legal distinction between a warning map and a regulation map.

A *warning map* aims to give technical information to planners. For example, "In this area, you have to take care of avalanches". This kind of map requires a further analysis in the case where human activities or structures are planned.

A *building regulation map* contains rules which must be enforced. It can be in the form of a general regulation or as a local law. The rules can forbid the construction of any building or require structural or architectural features on buildings in a defined area. As a result, a building regulation map can be considered as a passive and permanent prevention.

Phenomenon, Hazard and Risk Maps

"Hazard mapping" is a generic name. It can be used with different meanings according to the content of the map. Whereas a *phenomena map* contains information on the extension of the phenomenon and its dynamic properties. An actual *hazard map* is the result of comparing and evaluating information about the phenomenon and its frequency. A *risk map* takes into account hazards and human activities.

Three Examples in France

The CLPA

The French avalanche map CLPA (Carte de Localisation Probable des Avalanches) is a warning map of snow avalanche phenomena (Borrel, 1992). Its scale is 1/25,000. There is no information about the frequency of the avalanches. Moreover, the avalanche contour on each path is defined as the edge of all the observed or interpreted avalanches. From a legal point of view, this map has no part to play. The authorities in charge of naturalhazard prevention consult it in order to decide if any further actual risk analysis is required.

The ZERMOS Maps

ZERMOS (Zones Exposées aux Risques liés aux MOuvements du Sol et du sous-sol) maps contain information on the area threatened by landslides or slope instabilities Their scale is also 1/25,000. They define areas where geological phenomena have already occurred or where a geological interpretation shows signs of a hazard. They may indicate the repetition of some events or the feasibility of a protection system. They are not regulation maps. They just give evidence of a need for further analysis.

The PZEA

This acronym stands for Plan des Zones Exposées aux Avalanches. This 1/2,000-1/10,000 map is the result of an analysis which takes into account the likelihood of phenomena in an area, their return period and the threatened personnel or structures. It is a *risk map* even if buildings are the only concerns taken into account. There are three kinds of zones: red zones where building is forbidden, blue zones where construction constraints exist and white zones where there are no constraints. The PZEA is quoted in the general planning map which exists in each local community. As a result, it can be seen as a local law.

A CLASSIFICATION OF AVAILABLE TOOLS

In order to generate these different kinds of maps and depending on the source of the displayed information, several tools can be used. This suggests that in addition to the content and the legal points of view, a new criterion related to the origin of the map content becomes important. It can come from *direct field observations and measurements*, from *human interpretation and assessment* or from *application of methods or models*. For the design and implementation of a protection system such as those presented in section "Prevention", human interpretation and assessment as well as methods and models application are used.

For both these tasks, there exist several *available, classical and already in use tools*. These tools are going to be listed with a special emphasis on those which are computer-based. We will not look at the source of the input data required by these tools and the problem of the collection of field observations and measurements. The problem of recording output data will be discussed separately.

Display Tools

Usually, the information contained in the "hazard map" does not come from a direct observation but from interpretations or assessments produced by a specialist. For instance, the information in CLPA, comes from interpretation of aerial photographs. The choice of a protection system always consists, in part, of an assessment made by a specialist.

In this context of human made interpretation, few devices help the specialist making the decisions. For the CLPA drawing, a stereoscope allows the interpreters to see the terrain in 3D (Borrel, 1992). The engineer in charge of the drawing of a ZERMOS maptakes advantage of slope maps. Meanwhile, in interpretation, the part played by the tools still remains limited.

Models

More and more, models appear as necessary to fully describe hazards. The purpose of this paragraph is not to exhaust an analysis of existing models dedicated to slope related natural hazards but, to classify different families of existing tools.

Statistics, Mechanics or Empirical Knowledge ?

The existing models have quite different bases. Some are based on a statistical approach which performs well in the resolution of frequency and probability problems linked to the "hazard". In avalanches there exist methods for that purpose as presented by Bakkehøi and others (Bakkehøi, Domas and Lied, 1983). In the simulation of falling rocks, the uncertainty due to the bounce can be coped with through probabilistic methods.

Other models are based on mechanics. That means that the conservative equations are completed with behavior laws suggested by experiments. The resulting ordinary or partial differential equations can then be solved with analytical or numerical methods (Salm, Burkard and Gubler, 1990 ; Rapin, 1991b ; Faure, 1990).

Because, statistical and mechanical approaches cannot deal with all the processes involved in a natural hazard, some systems try to take advantage of the *empirical knowledge of specialists*. This is often implicit in many classical models or explicit in the case of expert systems (Bolognesi, 1993).

Meanwhile, most of the time, the programs used are based on these different approaches. For instance, the flow of an avalanche is modelled through a mechanical approach using equations deduced from empirical laws of material. The probabilistic approach described above for falling rocks is completed with ballistic computation (Azimi, personal communication).

Terrain Data Required

Most of the systems currently used in a systematic way in France and Europe are based on terrain profiles. Few systems are able to build these terrain profiles from, on the one hand, a contour lines map or a digital terrain model, and, on the other hand, a line drawn by the user on the interface. Hazard TERMOS is the only system presenting such an interactive behavior (Toppe, 1986).

But even in the situation where a model is applied, the user must be experienced. For instance, the definition of initial or boundary conditions for a propagation numerical model (avalanches or rock falls for instance) requires an assessment of what is going to happen in the fracture or in the starting zone (Salm, et al., 1990; Buisson and Charlier, 1993).

Recording Tools

The purpose of these tools is to record information coming from direct observations, human made interpretation or models.

Paper maps, files and forms are the oldest way to record data. Recently, the development of data base management systems, cartographic software and, naturally, geographical information systems (GIS) allows a systematic record of data. Updating and back up operations are quite easy to do (Borrel, 1992). Meanwhile, the connection between these computer based systems and modelling programs is still difficult to use in an efficient way. It can be done in a research context but certainly not in an engineering context.

NEW NEEDS

New needs have appeared these last few years in the area of slope related natural hazards prevention.

Firstly, these needs are related to a change in the position of the natural hazards specialists. In France, there used to be a period when an engineer was allowed to decide, alone, almost without any kind of discussion, if a house could be built or not, just because he was a civil servant. This period is ending. An engineer must now face the local authorities or community councils and present his opinion on the phenomena, on the hazards and on the risks. He

does not make the final decision alone anymore (Charlier and Decrop, 1992).
Secondly, another trend is related to the need for safety. For a long time, protection systems were set up in places where accidents have already occurred. Mapping was not systematic.

Formalization

Because he must convince his partners, the natural hazards specialist must formalize a large part of his job. He must declare the methods he uses and clearly define the assumptions he makes. Indeed, the knowledge on natural hazards is not complete at all. In any actual protection problem there is and there will be a lack of data or information. This means that, the engineer has and will always have to make assumptions. Now he must present and explain them to his partners. In other words, he must explain the rationale for his decisions.

Systematicity

More and more, risk assessment will be required everywhere, on all sites, anytime, before any equipment planning. Risk assessment will also be required in real-time situations, in an actual emergency context using all the existing data and all the available tools and methods. That means that field consulting or mapping becomes more and more a complex task.

Teaching and Negotiation

The job of a natural hazard engineer is becoming, at least, a teaching job and sometimes a negotiation job (Charlier and Decrop, 1992). The engineer presents his analysis and the local authorities give their opinion, not on the description of one particular phenomenon, but on the choice of this phenomenon. As a matter of fact, very often, it is their duty to select the level of prevention for a facility needing protection. The authorities are responsible for the safety of the territory of the local community. The best way to teach or to negotiate is to bring one or several maps produced with clear assumptions, then to allow the council to modify these assumptions and then display the consequences of these new assumptions on the same kind of maps.

NEW TERRAIN DATA BASES IN FRANCE

The terrain data required by the models which have been presented in the section "Models" were mainly terrain profiles, contour lines maps or digital elevation models. This information was difficult, very expensive and took a long time to obtain. As a matter of fact, specific digitisation was often necessary. The appearance of geographical data bases and exchange standards will open new opportunities for decision support systems.

Geographical Data Bases

David, Lamy, Salgé and Salgé (1993) give an up-to-date overview of the different sources of geographical reference data available in France. There are several geographical data bases. Some of them are already available; others will be available in the next years.

BD Topo

BD Topo contains the information equivalent to the content of a 1/25,000 map. The quality and the accuracy of this data base is adapted to a scale of 1/10,000.
It is composed of two geometric layers: a "planimetric" one for the roads, the power lines, the rivers, the vegetation, the buildings…; an "altimetric" one for the contour lines and the geodesic points. BDTopo is a data base topologically well defined.
The construction of this data base will be finished by 2005-2010. Fortunately, this construction started in mountainous areas where slope related phenomena occur! It will be updated every 4-7 years.

BD Carto

The content is that of a 1/100,000 map. In this data base, some objects are defined in 2D and topologically well structured. Information about vegetation and land-use is not structured. It is based on SPOT satellite images.
The construction of this data base will be finished by 1995.

Geographical Information Exchange Standards

The developments of these data bases will not be complete without the emergence of standards. As a matter of fact, the terrain data bases are to be used in different contexts with different computer systems (Geographical Information Systems, numerical modelling software…).
For that purpose, a standard adapted to the exchange of geographical data was developed in France (AFNOR, 1992). Interfaces compatible with this standard begin to appear in the distribution package of software allowing easy exchange between systems.

Applications

These new data bases permit the development of new decision support systems. The topographical information becomes easier and easier and less expensive to obtain. In the case of BDTopo, the costs are divided, at least, by two but the availability and the flexibility are the best advantages.

In the next years, new systems which are to be developed will take advantage of these data bases. The analysis of a new area or a new site will probably starts by an operation of terrain data downloading. Some systems already import files which are to be part of BD Topo.

NEW COMPUTER TOOLS

Simultaneously with the development of these new terrain data bases, new computer tools are being developed. These advances will probably meet the new needs already presented in this paper.

Topographical Analysis

The developments of advanced abilities in commercial GIS allow the intensive use of topographical analysis on an adapted scale (at least 1/10,000). This was already possible in a research context but not in an operational way. Structured digital elevation models are now a good base for the computation of slope and slope breaking lines maps. Other geomorphological features may be processed as well (Martin, 1994). Using multi-criteria logical models by coverage overlaying, topographical analysis programs may support the engineer in charge of natural hazards assessment.

Interface

New specific workstations allow the 3D vision of a couple of scanned aerial photographs. This interface ability connected to the properties which have just been presented may give a powerful working environment to produce a terrain interpretation.

Concerning the human-machine communication, the generalization of graphical interactive interfaces is obvious. In the context of negotiation presented above, these interfaces will allow the engineer to take into account the opinion of his partners by modifying a choice or an assumption and produce graphically the new results.

Assumptions Management

The ability to manage assumptions is surely not only based on the interface. It requires an efficient processing of these assumptions by the programs. This efficiency can simply come from the computing power of the workstation or from a specific architecture such as a Truth Maintenance System.

Information Systems

In order to be sure to use all the existing data and the available methods, an actual integration of these data bases with the different display and simulation tools appears as the best solution.

This integration can be done by coupling existing systems (Ke, 1990). Communications between data base modules and computing programs is often difficult but possible. One of the main problems is the choice of the interface: must we take the data base interface or the program one?

This integration can also be based on integrated single programs built for the purpose (Toppe, 1986). New software architecture may help in the development of these information systems.

Knowledge Based Systems

The architecture of knowledge based systems (KBS) is an interesting solution. By using object-centered knowledge representation systems (Rechenmann and Uvietta, 1991), spatial reasoning is possible (Buisson, 1990). Truth Maintenance Systems in KBS allow an efficient management of assumption (Euzenat, 1990). And above all, the ability of KBS to pipe different numerical programs is very helpful. The ELSA system is an example of what can be done for integration in a knowledge based system (Buisson and Charlier, 1993). The Xpent system dedicated to slope stability analysis is based on the same kind of architecture (Faure and Mascarelli, 1993).

Meanwhile, in order to propose a generic knowledge based kernel of spatial objects and methods, the ARSEN project (Buisson and Cligniez, 1994) started in Cemagref in 1993. This kernel is designed to be used for the development of future applications dedicated to decision support in environmental or natural hazards problems.

CONCLUSION

Do the new tools presented in the last part of this paper fit the new needs ? Obviously, the author thinks that the new data bases and the new tools will help in the development of decision support systems. But, we must remain very cautious.

Firstly, in spite of the tremendous and recent progress, we are sure that human experience will still remain the most important part of an actual and efficient slope-related hazards prevention policy.

Secondly, we must say that the new abilities of computer systems are not the absolute solution of problems encountered while developing decision support systems for natural hazard prevention. We do not think that using only fashion tools will, in the end, be efficient. If so, we would fail as the researchers who tried to develop expert systems for natural hazards in the same way as expert systems for medical diagnosis failed. In 1986, an analysis conducted in Cemagref for the preliminary development of an avalanche decision support system already pointed out some important features of such a system: spatial reasoning, connection to data bases and high user interaction. Since 1988, an object oriented knowledge base with a user-friendly interface has been developed in Cemagref. At present, this system is in its validation phase by use of terrain data and its use is evaluated in actual field consulting contexts.

Before starting a new project, we need a cautious analysis of the aims and the means. During the development we need time, funding and tools. And last, we need validation, evaluation and evolution.

This paper has presented the author's opinion on the present decision support systems for prevention of slope related natural hazards

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Flood Hazards

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MARINE FLOODS IN THE CASPIAN SEA'S NORTHERN PART

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KEYWORDS: marine floods, nagony, sgony

ABSTRACT

Wind-induced changes in the level of the northern Caspian Sea are described.

Caspian Sea is a reservoir with a constantly changing background level. Because of its being isolated from the Ocean the water balance of the sea is mostly dependent upon the flow of its rivers, which is in turn linked to global climate changes and the general damping of North Atlantic, Arctic and European regions creating the main features of Caspy's hydrological conditions. Thus, the substantial level fluctuations peculiar to Caspy in particular present an extremely complex sum of numerous components - general damping and evaporation from the surface of practically the whole of the northern hemisphere. Tectonic processes contribute a lot to the character of the fluctuations and recently industrial development started the further aggravation of the situation. Bottom surficial samplings prove the fact that within the last five centuries high- and low-level periods changed each other several times and the average range of the fluctuations is equal to that of 6 meters. This century's range amounts to 3.57 m (Figure 1).

Temporary non-periodical level fluctuations of anaemobaric nature (the so-called "sgony" and "nagony") occur throughout all the expanse of the coastline. It is respectively 1.5 m. and 5 to 7 m. high in southern and northern parts.

As to the Northern Caspy, there can be two certain regions distinguished which are characterized by the topmost value of sgony/nagony-fluctuations. These are western and north-western coastal parts to the north of the Astrakhan peninsula, including the estuary of the Volga river, and the north-eastern coastal part from the Ural mouth to Buzachy peninsula (Figure 2).

Nagon is a flow of wind-driven waters directed by "moryana" - a strong wind blowing from the sea to the coast and constant in direction and the time of duration. Nagons form a long wave-line flooding coastal sites. Villages, industrial and agricultural structures, roads and electrotransmitting communications are constantly being affected. It also often ruins fisheries and navigational devices.

Sgon or ebb is initiated and further on influenced by the wind blowing from the opposite direction. It causes drainage of the coastal shallow reservoirs and results in fish perishing.

As a rule sgony and nagony commence simultaneously in Caspy's northern part at different sites and are characterised by the similar weather conditions and processes. For instance, if nagon appears in the north-west, there is sure to be the ebb going on in the north-eastern part and vice versa.

Wind waves rising during the powerful floods and ebbs at the depths division line (dividing the Northern and the Middle parts of Caspy) grow as high as 5 to 6 meters and present a severe danger for ships belonging to the "river-sea" types enduring at the most 2.5 meter high waves.

The depths in the Northern parts of Caspy do not exceed 10 meters pitch, i.e., identical to the range of sgon/nagon fluctuations. Bottom and coast declivities are at that very insignificant (not more than 10 to 20 cm per km). The coastline here is a flat accumulative valley with vast sand banks. Hence, when some substantial floods occur the territories contiguous to the coast turn to be inundated at the length of 30-50 kilometers. On the contrary, during the ebb (sgon) kilometers and kilometers of land lay dry even farther than the usual coast bounds.

The synoptical processes' development causes the most intense storm activity in the Northern Caspy and is characterised first of all by the co-activity of the enforcing anti-cyclone formations moving to Kazakhstan and Middle Asia along the ultrapolar axis (primo) and a sufficiently obvious cyclonal activity upon the territories of the Europe-Pacific Region, the Black Sea and Northern Caucasus (secondo). The more intensive cyclone enforcement and anti-cyclone deepening become, the more vividly is storm activity expressed in the "intervening" zone.

Within the period of instrumentally supported observations there were 11 most prominent storm inundations registered in the Northern Caspy when the level rise was detected as exceeding the average values in height at more than one meter (Table 1).

The highest of them occurred between November 10-13, 1952, along the north-western side. All the way along from the town of Caspyisky (or Lagan) to the Bryanskaya Cosa the rise-level exceeded the average one at 4.5 m. A vast low-lying territory to the north and north-west from Caspy (17,000 km^2) was flooded, and in addition to this the sea protruded from 25 to 50 km in to the land. The intensity of the level rise at Bryanskaya Cosa site reached even 20 cm per hour. The ultimate rise at the sites was as follows: island Tyulenyi, 24.86m abs.; Bryanskaya Cosa, 24.68m abs.; Cochubey station, 24.53m abs.

That flood had a dramatic aftermath: according to the eye-witnesses' testimonies the water rushed along the natural indentations in a form of a 2 meter high wave at a stream velocity of 18 to 25 km/hour. Scores of fishing boats were swept away by the wave far into the wilderness. An uncountable quantity of cattle perished and people perished too.

This is how they describe it:

Chistaya Banka island: "On November 11 at 0.20 a.m. the island was all deep under the water... The depth amounted to 1.5 m. One could see the water splashing at the window-sills and all the machinery was carried upstairs..."

Tulenyi island: "... over half of the island is covered with water... Houses, industrial objects and all have drowned; the navigational devices are flooded".

Ganyushkino village: "On November 12 there was a severe wind blowing from the south-east; its speed amounted to 25 m/sec. A real wall of water was driven with the wind and the village and the adjoining sites were all flooded. Some people perished..."

The town of Caspyisky (Lagan): "The water was rushing at unbelievable speed, carrying along all it met and devastating the place. A few houses were actually swept along. All the transport boats and fishers were torn off the anchors and also carried far away into the steppe."

On its way to the west Caspian waters reached at some places the railway line Kizlyar-Astrakhan and washed it away at Ulan-Khall, White Lake, Cochubey for at least 50-70 meters in length. Commercial train communication was disconnected for three days.

The flood was caused by a persistent stormy wind from the east and south-east and the storm covered not only the northern regions but the Middle Caspy as well. Some hydrometeorological observational stations registered the wind velocity that had not occurred for the previous 40 years. At the peak of the nagon the wind power in the north-west reached the point of 12 balls. Nothing the like has yet been observed since then up to the present (Figure 2).

As can be seen from table 1, inundations like this take place in the north-western Caspy not more than once in 10 years (over 1 meter rise). Less intensive floods (less than 1m) may be observed once or twice a month (especially in autumn and winter). In summer nagony in the northern Caspy occur but seldom.

There is a lack of scientific information concerning north-eastern Caspy's nagony. Regular observations have not been carried out here for decades due to the complicated conditions in which the observations have to be carried out.

According to the scanty data from Prorva meteorological station (1933-1934) the peak level was observed on June 19,1934 and was equal to -24.75 m.abs., i.e., 168 cm higher than the average of this year. At Zhilaya Cosa station (1935-1937) the maximum was registered on June 11,1936 (-24.25 m.abs.).

The most powerful nagon occured on October 1958. Because of the stormy wind (20-28 m/sec) from the south-west and west directions all the coastline from Guriev (Ural river mouth) to Prorva station was inundated (20-30 km.). The thickness of water layer on the territory amounted to 0.25 to 1.1 m and the maximum rise (1.7m) was marked near the oil pipeline Teren'-Uzek (26.25m. abs.).

Nagon of March 25-26 1958, judging by the remaining traces of it, shifted the coastline to 35-40 km eastward from Prorva.

Sgony in North Caspy are also scarcely explored and mostly due to the extremely insignificant declivity of the bottom and the coast. The border of the drained territories unlike that of the inundated ones is faint and unevenly drawn. The water recedes remaining in hollows in the form of pools and lakes. The sand banks are bared and the area of the islands and banks increases although the definite border of the drained territories is difficult to distinguish, as a rule. The more sure method of defining the intensity of sgony is level registration, yet it does not always work as well. During the sgonys of high intensity registration is complicated by the sea's stepping back to several kilometres from the point of observation thus making it actually impossible. The levels in the remaining pools and lakes do not reflect the real values at the moment of the lowest level fall.

Substantial sgony in the north-west Caspy were observed nine times within the period from 1937 to 1994, i.e., once in six years (table 1). The most remarkable of them was observed on October 1,1978 when the sea level fell at Tulenyi island to -30.14m. abs.

That is what the witnesses say about one sgon in the North-East Caspy: "In the fall of 1935 our fisher was floating to the south of Prorva. On October 29 at night a strong west wind began to blow and the water was gradually driven away westwards. On October 31 the boat touched the bottom. In addition to that the boat was attacked by the drifting ice which formation began with the shallowing of the coastal waters. The fishers had to take measures and protect the boards from being pierced through. Yet the ice dried up on approaching the boat. We found ourselves being captives in the boat lying on the absolutely dry surface. And it was only on November 6 that the wind quietened and the water began to return."

The most complicated hydrological situation was to be observed during the whole year 1977 when the average level of Caspy fell to the lowest pitch (the first time for the whole 500 previous years) and was equal to -29.00m. abs. These low background levels accompanied by the frequent sgony created a crisis situation in the most shallow northern part of Caspy. The fish would perish and the transport was paralyzed.

Background levels' fluctuations linked to the changes of the income and expenditure parts of water balance seriously influence the intensity of sgony/nagony. Due to this fact within the period 1976-1994 the critical level points presenting danger for sea and river transport were re-calculated (in 1976, 1977, 1982, 1990, 1991, 1994).

Systematic scientific researches were started in the North Caspy in the end of the last century. And the information accumulated by the time allows the researchers to arrive at certain conclusions as far as the precise assessment of the fluctuations is concerned.

S.I.Kan was the first to suggest the method of short-term forecasting of North Caspy's levels (Kan 1948). The method is based upon working out the empiric interdependence between the sea level and the sgon/nagon-winds velocities and the value of the baric gradient. The direction of research work chosen proved to be effective and the modified method is still of great use in sea-floods' forecasting.

Sheremetevskaya developed another method of forecasting based on the study of atmospheric pressure presented as the expansion factors of Chebyshev's polynominal theorem (Sheremetevskaya 1964). The pressure is measured at 25 different points for the following characteristic situations: strong nagony and sgony, some slight level fluctuations. The worked out functions allow us to forecast sea level changes 6 to 24 hours beforehand. It is proved that the intensity of sgony and their values are dependent on the depth of the place, hence the most substantial sgony take place at the depth-division line (2-3 m isobats). As the average sea level gets lower zones of maximum sgon/nagon values are shifted seawards, and as the average rises they move landwards. Due to this it appears impossible to use long observations' data to get precise statistical characteristics of the processes applied to some definite point.

Substantial changes of sgon/nagon level fluctuations in North Caspy may occur at the level falling lower than that of 30 to 31m and the eastern part of the sea separates from the western one.

Observations of the levels and currents on the sections perpendicular to the coastline proved that at the very beginning of nagon its maximum height zone is distributed along the coast at some definite depth and further on it shifts landwards and vice versa for sgons - seawards. The maximum nagon zone is usually to be found not far from the coast and as to sgon's maximum - close to the territory with 2 to 3 m isobat. It was also found that there exists a critical at-coastal depth where sgony and nagony are compensated by a bottom gradient current. When the winds are strong the depth is detected as 1.5-1.9 m. The higher the wind velocity is, the higher is the critical depth value. For territories with depths lower than the critical one all the water flow from the surface to the bottom is moved windwards and the latter process causes the highest level rise for nagon and the lowest one - for sgon. The values characteristic to sgony and nagony for the insignificant land and coast declivities have the tendency of decreasing throughout all the way from the critical depth area both seawards and landwards.

A detailed description of sgon/nagon level fluctuations characteristics for the northern part of Caspy is given by Scriptunova and Gershtansky (Scriptunova 1967; Gershtansky 1978).

Gershtansky did some research work on the mechanism of sgon/nagon formation and on the conditions accompanying the transformation of surficial waters' profiles at their different phases for the shallow coasts, estuaries and the deeper sea areas (Gershtansky 1978; Gershtansky and Kazakov 1980). His suggestions touched on the typification of the synoptical processes leading to the north-western Caspy's flooding and the opportunities of its usage for forecasting. Unfortunately, the author considered but the situations with the Caspy's background levels low and it was thought they were only going to get as low as -30 to 32 m. abs.

There were also developed other methods of sea floods' forecasting for the northern part of Caspy but all of them require precise and detailed information on the actual conditions of the atmosphere pressure, wind directions and velocities and the levels which are difficult to collect.

For decades observations of the coastline movement and research works on the flooded territories for sgon/nagon conditions were carried out only episodically. It was only in 1964 that aviation was for the first time used for observational purposes, and satellite photography was for the first time exploited in 1980. With their help the borders of inundated areas were registered and marked on maps.

The author of this article in 1986 carried out pioneering research work on the formation of nagony in winter time when some part of the coastal territory is covered with ice. It was found out that only "pripuy" - the stationary ice tied tight to the land has a serious influence upon the character of nagony (restrains the process). That ice cover is formed only in severe winters and is actually spread over the whole of the northern part of the sea. It is such a solid formation that it is even able to withstand storms. At the thickness of the ice layer equal to 30 cm and more the wave of nagon coming from the open sea is quickly subdued by pripuy and reaches the land rather weakened. The wider the pripuy zone is, the more effectively are the waves subdued. In warm winters the ice layer is very fragile and uneven so that strong winds easily break it through and the drifting ice slows but short wind waves while the longer ones go through without any hindrance. Then the flood is as strong as it may be in any other season.

Litvin Y.A. carried out some estimations of sgon/nagon parameters in the north-western Caspy basing them on the statistical analysis of hydrometeorological information. He presented an estimation of energetical characteristics for storms causing substantial nagony and their statistical parameters. For the basis of the estimations there was taken the sum of products of storm activity durations multiplied by the square of the wind velocities' projection on one of the effective nagony directions /E/:

$$E = \sum_{i=1}^{n} \left[(v \cos \varphi) 2\Delta t \right]$$

The storm analysis and the comparison of E values with the values of nagony level rises allow us to state the lowest range of dangerous nagony. It is equal to 3000 (E=3000). With E<3000 the nagony height as a rule does not exceed 0.4 m. The danger of serious flood formation increases with E>3000. The earlier arrived at conclusions concerning the lessening of nagony's height in winter in comparison with that of the other seasons (2 to 2.5 times) were quantitatively proved. The energetically identical storms were compared.

1978 opened the epoch of the next serious sea transgression. By the beginning of 1995 the total rise of the background water level compared with the lowest one observed in 1977 (29.00 m.abs) has already amounted to approximately 2.5 m. Caspy's transgression is still going on. The low-lying territories formerly inundated but episodically have become by now part of the sea. Now we have the territories constantly being flooded where the water would not reach even during the most dramatic inundations. Nagony have increassed substantially in the estuaries of Volga and Ural rivers. The sea transgression has led to disappearing of the so-called buffer zone between delta and the sea that used to slow nagon waves during the periods of the low sea levels thus preventing the floods from penetrating into the delta. Now when the sea level is constantly rising the most important scientific-technological task is to develop and to practically realize a complex system of activities aimed at the protection of the shores and mouths from floods. The task calls for serious scientific researches and further studying of the dangerous natural phenomena.

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Table 1. The Most Significant Sgony And Nagony in the North-Western Part of the Caspian Sea

Nagony						Sgony		
Year	Date	Maximum Level m.abs	Rise Value m	Intensity of the Rise cm/hr	Flood Zone Width km	Year	Date	Minimum Level m.abs
1877			3.6			1957	09.10	-29.83
1910	25-27 Nov		3.6			1960	21.01	-29.92
1952	10-13 Nov	-24.53	4.5	to 20	to 50	1963	26.11	-29.90
1960	19-20 Nov	-26.95	2.0	4-10	10-17	1964	29.01	-30.00
1981	27-30 Dec	-26.16	1.8	to 14	to 40	1965	26.10	-29.80
1984	25-28 Jan	-26.84	1.5	4-14	20-30	1977	13.09	-30.04
1989	17-18 Apr	-26.20	1.4	4-9	20-30	1977	02.10	-30.02
1991	03.06	25.95	1.1	5	20-25	1978	01.10	-30.14
1992	08.04	-25.78	1.4	4-7	15-20	1981	03.02	-29.73
1993	2-3	-25.76	1.4	3-4	12-17			
1994	7-9 Apr	-25.20	1.8	to 12	25-30			

Figure 1. Secular variations of the Caspian Sea level

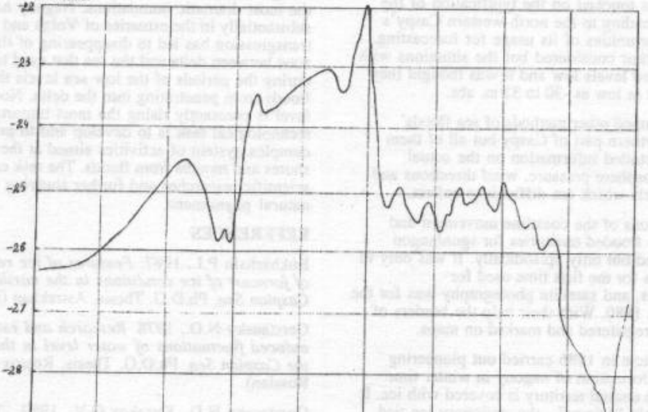
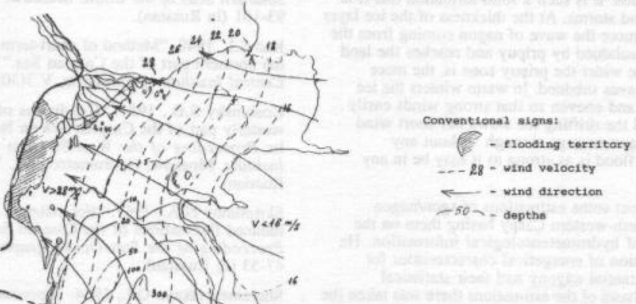


Figure 2. Hydrosynoptical conditions of flooding in the north-westerly part of the Caspian Sea on November 10-13, 1952.



SEISMIC METHODS OF TROPICAL CYCLONE INVESTIGATION

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ABSTRACT

An approach is described and illustrated for the study of tropical cyclones via microseismic processes occurring in the geophysical environment under their impact.

INTRODUCTION

Tropical cyclones (TC, hurricanes, or typhoons) can be related to major disastrous and destructive natural phenomena. A problem facing science is to develop techniques and facilities with the capability to diminish their tragic affect.

Solutions to this problem can be realized in two ways: the development of forecasts of tropical cyclones' movement and evolution; and the development of techniques of impacting cyclones with a view to weakening them.

DESCRIPTION OF THE PROPOSED APPROACH

Studies of TCs were started long ago. A certain ideology of studies has taken shape. But, tropical cyclones are far too complicated, and the processes occurring in them are serious research problems.

It is characteristic of TC studies, particularly, that they always deal directly with the processes occurring in the centre of a TC or in its close periphery, and are based on the results of direct measurements. Measurements of the parameters are made at sites of stationary observations, on board a ship or an aircraft, or via satellite. Stations for making constant meteorological observations are mainly located on the continents and are often far from the active zone of TC development, which cannot but influence information authenticity. Aircraft and ship cruises are rather rare. For effectiveness they must be carried out on a regular and constant basis, but that requires great financial means. There are also problems with satellites' observation facilities. We believe that for studying such a complex subject as TCs, some principally new techniques are needed along with those used previously.

TCs are not isolated phenomena; and, having great energy, they influence the processes occurring in the ocean and the Earth's crust, the relatively remote lower atmospheric periphery, possibly the ionospheric layers, etc. (Khain and Sutyrin 1983, Yeruschenkov *et al.* 1990).

The proposed approach is that TCs should be studied via the processes occurring in the geophysical environment under their impact. In fact, this approach is tackling the inverse task. The usefulness of such an approach is quite reasonable. Reasoning from the reactions occurring in the geophysical environment, it is possible to detect new particulars of TCs. Besides, TC studies involve facilities and techniques applied in allied geophysical branches.

It has long been known that TC movement has an effect on layers of the Earth's crust through the ocean. Under such a process microseismic waves are produced—storm microseismic waves (SMW) (Tabulevich 1986)—which have been studied long ago. Seismologists tackled different problems, related naturally to seismology. Technical means of SMW registration and processing could not at that time lead to essential results of an applied character.

Presently, the situation has substantially changed. Many seismic stations perform registration of data in a digital computerized form on a regular round–the–clock basis. A great number of seismic stations can be counted today and the tropical zones are fairly covered by them. In contrast to meteorological stations, the distance from seismic stations to a tropical cyclone is of no importance under certain adjustments of instruments. It would be rather more important to know the seismic tracks. The real distances of TC tracks to many stations in combination with seismic waves' speed suggest the possibility of SMW registration a on real–time basis. The seismic stations are generally provided with computers and reliable communications facilities, which is of vital importance under simultaneous fast processing of data for a number of stations. Information on the earthquake is valuable for seismologists; the information we need is considered as background for seismologists, hence expenses for its acquisition are relatively small. The above considerations clearly demonstrate the possibilities of seismic stations in studying TCs.

Before going into investigations of SMW we stated a number of problems: to find out what new information on TC structure or developing processes can be obtained via seismic research techniques; how it is possible to produce fast evaluation of major TC parameters based on seismic information; and, what would be a research policy. Thus, our tasks differed from those which had been carried out by seismologists previously: they should principally be of an applied character.

Archived seismograms have been used in the work which had been recorded at a number of seismic stations in the USA, Japan, and China. We needed seismograms for the days when particularly powerful TCs occurred. But the archive has been based on earthquakes. That is why most often we had to choose seismic information which did not correlate with TCs of interest to us, and we had to consider the cyclones for which information was available.

We considered seismogram fragments of one hour with a discrete spacing of one second. Two fragments were analysed daily: at 00.00 and 12.00 GMT. Below the results are briefly given by fragments.

DETECTING AND TRACING TROPICAL CYCLONE MOVEMENT

A variant of the TC detection technique is proposed as well as tracing its movement using SMW parameters.

A region is chosen, characterized by high occurrence of tropical cyclones. It may be, for example, the region confined within a rectangle of 0–50N and 100–180E. A set of seismic stations is then selected, preferably those disposed bilaterally along the chosen region for all stations. The region is divided into squares, e.g. 2x2 degrees. The distance from the station to the center of each square is calculated for all stations. For any fixed point in the region the ratio between SMW amplitudes registered at two stations (for one and the same period, T) is a constant value and does not depend on the source energy. For the center of each of the squares the ratio of amplitudes is calculated in pairs for all stations combined in any way (Yaroshevich *et al.* 1994):

$$\frac{A_{ik}}{A_{jk}} = \frac{R_{jk}^2}{R_{ik}^2} \times \frac{\beta + R_{ik}\sqrt{R_{ik}}}{\beta + R_{jk}\sqrt{R_{jk}}} \exp\left[\alpha(T) \times \frac{\left|R_{jk} - R_{ik}\right|}{2}\right] \quad (1)$$

where A_{ij} is the amplitude of a microseismic wave at the proper station for a specific period T; R is the distance from the source of SMW to the observation point; $\alpha(T)$ is the coefficient of SMW attenuation; β is a coefficient characterizing the relationship among volume and surface waves; i,j is the station's numbering; and, k is the number of the square. A great diversity of values (1), determined by the number of stations, squares, and values T, is entered into a personal computer.

Using values A (for the same values of T) measured at different stations within one and the same GMT period (1-2 hours), the relations $(A_i/A_j)m$ are arranged in pairs for each pair of stations. With the help of a computer the area of possible source position is determined using the following inequality:

$$\left|\frac{A_{ic}}{A_{jc}} - \frac{A_{im}}{A_{jm}}\right| \leq \sigma \quad (2)$$

where (A_{ic}/A_{jc}) and (A_{im}/A_{jm}) are calculated from (1) and the relation of the measured amplitudes, respectively, and σ is a specified range of the values' spread. The overlapping of areas, determined from (2) for all pairs of stations, detects the decreased area of SMW source location. The size of the decreased area is governed by an optimal number of stations, sets of values A and T, and accuracy in their measurement. The first TC position can result in an area of about 10x10 degrees square.

This is an important result which makes possible fast detection of an area of particular interest to the scientists studying TCs, and to meteorological and navigational services. On occasion, specialists studying tsunamis of meteorological origin should be aware of this.

Further tracking of TCs is somewhat easier. The calculations are made within a reasonable vicinity of an area of the initial TC position. This vicinity is determined from the time interval between the earlier and later determination of TC position, possible speed of its movement, and an operator's skill.

At the very start of technique testing we had a rather small amount of information; the number of stations was also insignificant. As a result, the discrepancy between TC coordinates, determined on the basis of meteorological data and SMW, was relatively large and amounted to 3-4. With sufficient amounts of information, an optimal number of stations, and thorough determination of parameter values A and T, the accuracy of calculating TC positions will be improved. Of prime importance in this technique is the possibility of constantly tracking TC movement.

ON THE PERIODS OF STORM MICROSEISMS

It is commonly supposed that the source of SMWs is the TC; SMWs are directly generated by wind oceanic waves produced by cyclones. For the most part, the total energy of wind waves is in the range of periods of about 4-25s, which are probably considered as a range of SMW periods. The best known theories of the mechanism generating SMWs are related to the theory of standing wind waves, emerging mainly in the rear part of TCs, and a "surf" theory. According to the first theory, periods of SMWs are two times less than those of wind waves. By the second "tidal" mechanism, SMWs with periods of approximately 20s are generated at the expense of hurricane waves moving from TCs to the shelf (Tabulevich 1986).

The spectral analysis of SMWs suggested that under great changes of TC intensity the values of SMW amplitudes within 4-6s should change the same way, which is consistent with either of the two theories mentioned above. However, we have detected waves whose period was several tens of seconds. As a TC is strengthened (or depressed) the range of amplitudes is identically changed within great and small periods (Fig. 1). Reasoning from this, we can come to the conclusion that the whole range of SMWs under consideration (4-100s) is of a common origin—tropical cyclones.

The result obtained is an interesting one by itself, but needs further investigations to be made. The result was found useful in solving one applied task given below.

In the given context two notes should be made. SMWs with periods of tens of seconds can not be accounted for by the above theories, hence it is necessary to specify the mechanism generating storm microseisms. And second, for many years seismic information has been registered via photorecord. The microseisms' parameters have been manually registered and strictly within the ranges where the latter were distinctly viewed. Considering the amplitude and frequency characteristics of the available seismographs, the representative ranges of SMWs could hardly be obtained. Only at present has it become possible, solely on the basis of information from those stations where the data are registered on computer media, and under certain characteristics of the seismographs.

ON THE SIGNS OF IDENTIFYING STORM MICROSEISMS

It is in fact an ordinary matter that a seismogram results from the superposition of a number of seismic signals (earthquakes, their "tails", SMWs, etc.). We had to produce signs for identifying the sources against the background of the seismograms, since an analysis of SMWs is justified only if other signals can be neglected. It is particularly difficult if the values of SMWs and the earthquakes are comparable.

It appeared that spectral analysis would allow us to come close to solving this problem. We succeeded in finding out the fact that in the absence of clear evidence of earthquakes, the amplitude spectrum of SMWs in the range of periods of 4–80s has one pronounced peak within a range of 5–8s. This situation occurred when no severe or close earthquakes took place for approximately 5–10 hours prior to the analyzed fragment of SMWs. In Fig.2 the amplitude spectra (in representative units) of SMW seismograms registered at several seismic stations are given.

Typically, no severe earthquakes had been identified since long before these seismograms were registered according to the "Seismological Bulletin." Thus, it is believed that the prevailing signals on the seismograms are those of SMWs. In Figures 2a, 2b, 2c, and 2d, SMW spectra are given for 00.00 GMT 28.09.1992 (TC "Ward") at the following stations respectively: "MAJO" (36,542N-138,209E), "ANMO" (34,946N-106,456W), "PAS" (34,148N-118,172W), and "KIP" (24,423N-158,015W); in Figure 2e and 2f, for 12.00 GMT 20.11.1992 (TC "Gay") at stations "PAS" and "KIP," respectively. It is seen from these Figures that despite the different geographical locations of the seismic stations, the effect is identical.

If an earthquake occurs, two and more clearly pronounced peaks emerge in SMW spectra. The first one is produced at the same area that would prove a cyclone "presence;" the rest of other peaks are shifted to the area of large periods, 20 and more seconds (Fig.3). Most often this takes place when an earthquake occurs shortly before the SMW fragment is considered, or if a severe earthquake occurs. The height of peaks in a spectrum depends on the source's impact and the form of frequency characteristics of the seismographs.

In Figure 3 the spectra of SMW amplitudes are given for (22.11.92, 12.00 GMT) seismostations "PAS" (1) and "KIP" (2). These seismograms are probably suggestive of certain impacts of the earthquake "tail."

Thus, we have obtained the first possibility of fast–detecting seismograms using the spectrum, where the main signal is that of SMW. Applying such seismograms we improve the accuracy of determination of TC parameters, thereby increasing the efficiency of calculations for TC forecasting. Apart from this, the results obtained may also prove to be interesting for seismology.

ESTIMATION OF VARIATION IN TROPICAL CYCLONE INTENSITY

Along with determining the TC position, a possibility of estimating the relative variation of its intensity has been identified. Considering the typical speed of variation in energetics' parameters of TC intensity, it would be sufficient to make estimation of it every 3–4 hours.

We have shown that with the "classic" periods of SMWs (5–10s) TC intensity variations are not necessarily tracked against the amplitude background. This occurs more often than not within the periods 60–100s, which once again proves their cyclone origin (Yaroshevich and Yakhryushin in publication).

But in some cases, it has been found that with the increase of TC intensity the values of amplitudes have suddenly been decreased for the whole range of periods. This has been noticed on all sides of the cyclone, which relates in our opinion to the mechanism of SMW generation within a wide range of frequencies. We have noticed that more effective in tracking the TC intensity was the parameter characterizing the relationship between the mean amplitude (amplitude square) calculated for the range of large periods (e.g. 60-100s), and the amplitude similarly calculated for the range of small periods (e.g. 10-15s).

The above considerations are demonstrated in Figures 4a and 4b with the cyclone "Omar" (1992) taken as an example. It should be noted here that only those days have been considered, as in other cases, when no extraneous signals were observed in seismogram spectra.

Curve 1 in Figure 4a is the lapse of pressure (DeltaP = 1020 mb – Pmin); where, 1020 mb = pressure outside the cyclone; and, Pmin = pressure in the center of the cyclone (one of the characteristics of TC intensity). The curves of squares ratio for mean amplitudes (A1*A1/A2*A2): are also given here; curve 2—station "KIP," where A1 is calculated for the range of periods 50–120s, and A2 for the range 10–12s; and, curve 3—station "ANMO," where A1 is calculated for the range 50–120s, and A2, 12–15s.

In Figure 4b the dynamics of mean amplitude A (representative units) are shown for the station "ANMO" for the same days: 1,2,3 correspondingly for the ranges 5–6s, 50–120s, 12–16s. It is seen from the Figure that for the given case, mean amplitudes for both small and large periods are not characteristic of the development of cyclone intensity. The marked trend of cyclone activity would rather be tracked via the ratio of amplitudes. In many papers published long ago, it was noticed that with cyclone escalation, a rise of amplitudes within "classic" periods of SMWs was also observed. Altogether, we do not deny this fact. But one point should be noted: in those papers the comparison was generally given of the days for which the difference in values of Pmin was maximal. As to us, we were striving to find out characteristics of minor variations in the development of cyclone activity.

It is necessary to emphasize that every station is characterized by its individual particulars. That is why the range of periods as well as types of seismic channels should be thoroughly selected for each of the stations.

CONCLUSIONS

If we consider the results given in the context of their applied usage we may speak of the beginning of TC investigations via seismic techniques. Active studies in this field would tangibly promote not only TC investigations, but undoubltly enrich the knowledge of the processes occurring in the allied geophysical environment. Deepening of those studies may be of interest to the USA, Japan, China, and other countries, particularly to their meteorological and seismic services.

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FIGURES

Fig. 1. Amplitude spectra of SMW registered at the "ANMO" station:
1 - September 28, 1992, 00 GMT, Pmin = 990 mb;
2 - October 3, 1992, 00 GMT, Pmin = 945 mb.

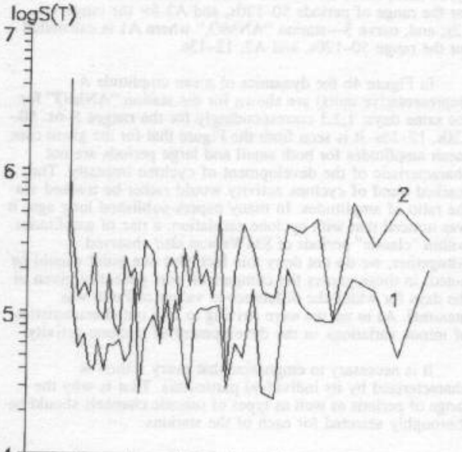


Fig. 2. Amplitude spectra of "pure" SMW from different seismic stations.

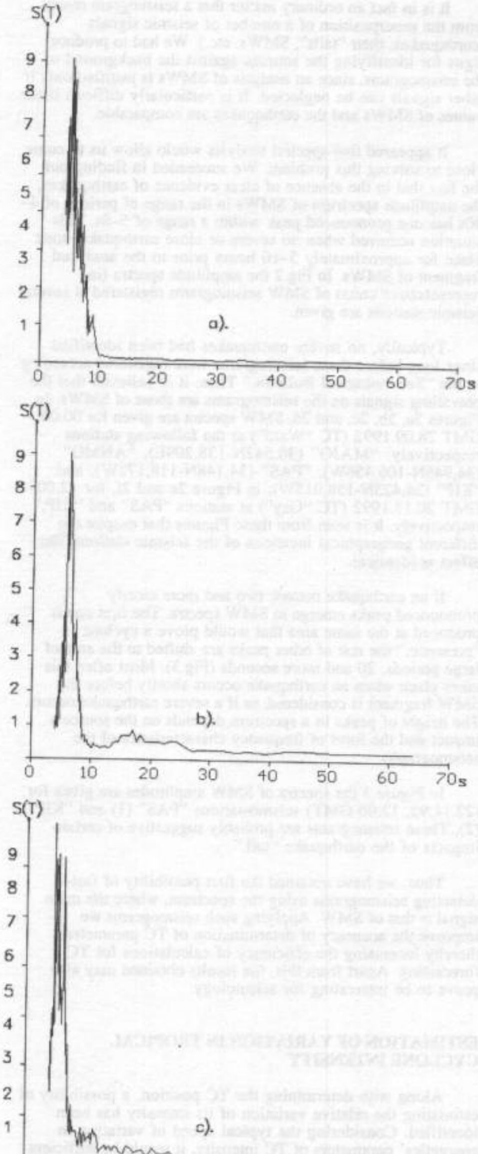


Fig. 2 (continued).

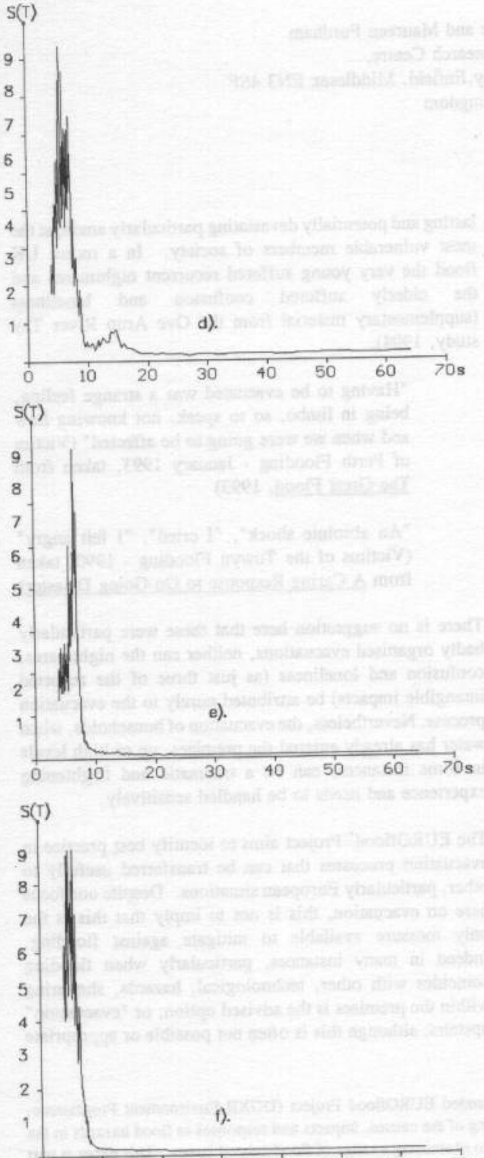


Fig. 3. Amplitude spectra of SMW in the case of superposition of signals.

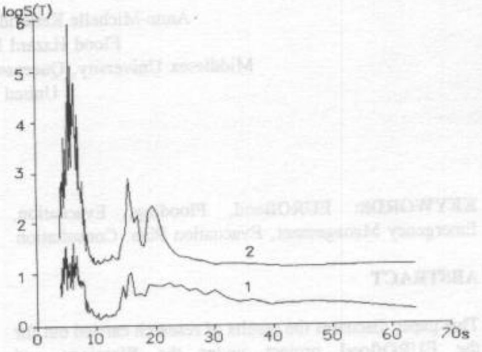


Fig. 4a. Pressure drop (DeltaP) in cyclone (1); ratio of squared average amplitudes of SMW from the "KIP" station (2), and from the "ANMO" station (3).

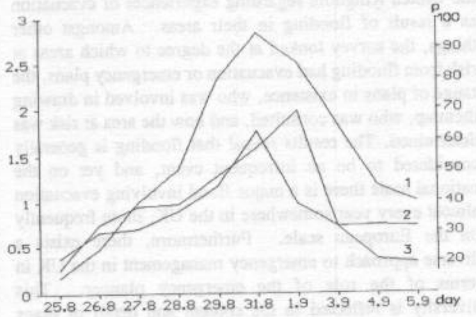
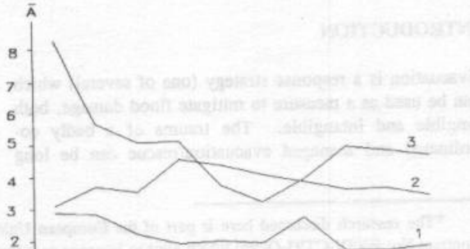


Fig. 4b. The change in the average amplitudes of SMW over the ranges:
1: (5–6)s; 2: (50–120)s; 3: (12–15)s.



EUROFLOOD[*] UK EVACUATION STUDY: INTERIM RESULTS

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KEYWORDS: EUROflood, Flooding, Evacuation, Emergency Management, Evacuation Plan, Consultation

ABSTRACT

This paper discusses the results of research carried out for the EUROflood project under the Warnings and Intervention Strategies module, which has a major focus on evacuation. This involved undertaking a comprehensive survey of Emergency Planning Officers in the United Kingdom regarding experiences of evacuation as a result of flooding in their areas. Amongst other things, the survey looked at the degree to which areas at risk from flooding had evacuation or emergency plans, the range of plans in existence, who was involved in drawing them up, who was consulted, and how the area at risk was determined. The results reveal that flooding is generally considered to be an infrequent event, and yet on the national scale there is a major flood involving evacuation almost every year somewhere in the UK, more frequently on the European scale. Furthermore, there exists a diverse approach to emergency management in the UK in terms of the role of the emergency planner. This diversity is reflected in the content and detail of plans when looking across regions, undoubtedly influencing the ensuing emergency response, and overall evacuation, be it for flooding or other hazards.

INTRODUCTION

Evacuation is a response strategy (one of several) which can be used as a measure to mitigate flood damage, both tangible and intangible. The trauma of a badly co-ordinated and managed evacuation/rescue can be long lasting and potentially devastating particularly amongst the most vulnerable members of society. In a recent UK flood the very young suffered recurrent nightmares and the elderly suffered confusion and loneliness (supplementary material from the Ove Arup River Tay study, 1994).

> "Having to be evacuated was a strange feeling, being in limbo, so to speak, not knowing how and when we were going to be affected" (Victim of Perth Flooding - January 1993, taken from The Great Flood, 1993)
>
> "An absolute shock", "I cried", "I felt angry" (Victims of the Towyn Flooding - 1990, taken from A Caring Response to On-Going Disaster)

There is no suggestion here that these were particularly badly organised evacuations, neither can the nightmares, confusion and loneliness (as just three of the reported intangible impacts) be attributed purely to the evacuation process. Nevertheless, the evacuation of households, when water has already entered the premises, up to high levels in some instances, can be a traumatic and frightening experience and needs to be handled sensitively.

The EUROflood[*] Project aims to identify best practice in evacuation processes that can be transferred usefully to other, particularly European situations. Despite our focus here on evacuation, this is not to imply that this is the only measure available to mitigate against flooding. Indeed in many instances, particularly when flooding coincides with other, technological, hazards, sheltering within the premises is the advised option; or "evacuation" upstairs; although this is often not possible or appropriate

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[*]The research discussed here is part of the European Union funded EUROflood Project (DGXII Environment Programme, Contract No: EV5V-CT93-0296) which aims to improve understanding of the causes, impacts and responses to flood hazards in the European Union. The project involves a multi-disciplinary approach to examining a range of flood-related issues. This paper is part of the Warning and Intervention Strategies Module, where the UK is being used as a case study of the current situation in Europe.

for those living in single storey buildings and ground floor flats.

Evacuation is usually necessary when flooding lasts for a substantial period of time, when there can be serious health and safety risks involved. The difficulties arising from a lack of electricity or heating can also warrant leaving, or evacuating, premises. This paper does not discuss in any detail whether evacuation is always the appropriate measure but concentrates on the **process** leading to this decision.

Evacuation is a complex social process (Sorensen et al, 1987) and has been studied from a number of standpoints in the past, indeed it has been developed into a prominent subject area of its own and thus has attracted much debate. However, most of this research has been undertaken in the United States, focusing on the US (Otway, 1989), which has led to many findings being supplanted into the European context, with little consideration of the cultural, political, historical, geographical and legal differences between the two continents.

Our research is just one small step in attempting to correct this "evacuation myopia" with a specific focus on flooding as a potentially disastrous hazard, of which there has been little recent detailed study either side of the Atlantic.

For the purposes of our study, we have taken **evacuation** as meaning any organised movement of people away from a disaster event, or any potential disaster event, for reasons of safety or protection, for any period of time, and an **evacuation plan** as a strategy for moving people from a place of relative danger to a place of relative safety (Perry, 1985)

METHODOLOGY

As part of the EUROflood Warnings and Intervention Strategies Module, this research element has focused on the responses from a questionnaire sent out to all County and Regional Emergency Planning Officers, or related title, in the UK. This amounted to a total of 74 areas from which 64 replies (approx. 86% response rate) have been received over a period of three months since the beginning of the study in August 1994 (Figure 1).

The questionnaire covered a range of issues concerning flooding, experience of evacuation, existence of plans, contents of those plans, details of who was involved in drawing them up, their availability and use, and some of the issues uncovered in other evacuation studies, carried out principally in the USA.

In some cases the questionnaire was followed up and supplemented by telephone interviews where it was felt that there was further information needed for clarification or if the EPO requested that the questionnaire be conducted in this way. Emergency Planning in the UK has not been seen as a major priority by government particularly since the demise of the threat posed by the Cold War, and Emergency Planning budgets tend to reflect this. This point puts much of what the questionnaire uncovered into context, the context of "parlous financial state of local government" (EPO, pers.comm.) restricting emergency planning departments' feasible workload and scope, and indeed the time available to complete the questionnaire. Although the complex question of finance was touched on, it did not form a central theme to our research in this instance.

The emphasis here on the role of the Local Authority Emergency Planners is not to deny that others, such as the police and other LA departments, also have a major role in the carrying out of an evacuation. However the Emergency Planning Officer is concerned with the planning, preparedness and response (Parker 1991). S/he has the role of co-ordination and management of the response to a disaster, often setting up the emergency co-ordination centre and bringing together all those involved in the response, and ensuring a smooth link between the response during a disaster, and the response after a disaster.

"DEVOLUTION" OF UK EMERGENCY MANAGEMENT

Contacting Emergency Planners around the country, it was soon discovered that even within one member state of the European Union, there was much diversity in who actually had the responsibility of Emergency Planning Officer. In some cases it was a matter of title - other titles included Civil Protection Officer, County Civil Protection Planning Officer, Emergency Manager. In other cases variation was found in the department to which the Emergency Planning Officer (or officer responsible for dealing with emergencies) was attached. Officers were part of the Fire and Civil Defence Authority; the Fire and Rescue Service; the Department for Housing and Environmental Services; and the Chief Executive's Department.

This variation has inevitably led to some difference in interpretation of the emergency management role around the different counties and regions. In some cases this difference of interpretation may well have more to do with the perceived risk of a particular area from any hazard which has determined the department within a local authority to which an Emergency Planning Officer is responsible.

This highlights a key issue in the emergency management debate, one that is echoed throughout the findings of the questionnaire, whether the devolution of coordination to the County/Regional level has led to the areas having too divergent approaches to emergency management or whether a diversity of approaches is a necessary response to a complex, variable, spatial and institutional situation (Krebs 1992).

National legislation (e.g. The Civil Defence Act of 1949 and subsequent Statutory Instruments) does guide the UK emergency planner through his/her responsibilities at a general level - the requirement that all emergency planning teams have County-wide contingency plans for example - but there is still much that is left to individual judgement. This can obviously lead to expectations differing across the UK in terms of what the EPO provides and what the individual will be prepared to do for himself/herself. The role of the EPO in a flooding incident is a case in point. In some instances s/he may take the lead control in coordinating a response effort, in others s/he may be limited to taking a participatory role. This can cause confusion in the public's perception of who is responsible for what during an emergency, with the result that often the police become the focus of all questions, queries and even criticism.

Perhaps it is not so much the divergent approaches which are at issue here but the national role of central government and the lack of a centralised information-dissemination body, sufficiently well-resourced to pass on lessons learned from a wide range of disasters. Floods are infrequent events and in many regions there may only be one flood during that EPO's employment and thus little opportunity to learn from experience and improve systems. Yet on a national scale there is a major flood almost every year in the UK from which many useful lessons could be learned. As a result of this potential lack of dissemination, there can be duplication of effort, resources and indeed lessons learnt from individual incidents when counties/regions are unaware of reports and exercises that already exist. After all, one of the objectives of comprehensive and integrated emergency management is to use resources more efficiently (Perry, 1985)

More positively, the UK Home Office Emergency Planning College at Easingwold does in many respects resolve this problem with its regular courses, seminars and workshops designed for emergency planners *(eg Introduction to Emergency Management; Rest Centre Management; Civil and Military Co-Operation in Emergencies; etc.)* and library containing reports, plans, books, journal articles, etc. However, the library is far from complete as it is discretionary for individual authorities to submit their incident and exercise reports. There is also the Emergency Planning Society who meet on a regular basis, and the quarterly Civil Protection newsletter, both offering good opportunities to disseminate the lessons learnt from one region to another.

Whilst in theory, the existence of these opportunities is promising, the practice is the often limited due to restrictions on finances and time, with the result that these resources are in general underutilised. In addition it has been reported elsewhere that there lacks the intercourse between researchers and practitioners to support the required policy (Parker 1991).

EMERGENCY EVACUATION PLANS

Our analysis has focused on the evolution, existence and contents of emergency plans which cover evacuation as a result of flooding. There is no national guidance in the UK as to what should and should not be included in an emergency plan, be it an evacuation plan, a flood plan or a generic plan covering a range of emergency events. Indeed the range and combination of plans in the possession of the Emergency Planning Officer varies greatly across the UK.

Some EPOs dispute the usefulness of plans as they fear they will compromise the flexibility required for dealing with the wide range of usually unforeseen problems they have to manage. However, verbal and informal agreements are often made, based on individual personalities. These can disappear with the retirement or departure of the EPO or other member of a coordinating group (Penning-Rowsell et al 1994), a planned response to hazards is a necessity according to White (1974) and it can also be argued that their preparation and use are useful exercises in themselves as individuals formalise and familiarise themselves with the intricate parts and how they function as a whole. The Home Office, in its recently updated report Dealing with Disaster, itself recommends their use for reducing "the likelihood of errors resulting from decisions being taken under crisis conditions" (p.2, 1992).

The responses to the questionnaire showed that 36% of Local Authority areas do not have any kind of plan covering evacuation for flooding, and yet 88% of EPOs admitted that at least part of their area is at risk from flooding (Figure 2). This finding raises a question concerning the factors involved in deciding the type and level of detail of the emergency plan. The range of plans in existence which would cover evacuation in cases of flooding varied from actual 'flood evacuation plans' (11%), 'flood plans' on their own or together with the 'generic emergency plan' (15%), 'comprehensive generic emergency plans' (23%), and 'generic evacuation plans' (9%) - making direct comparison difficult.

It was hypothesized that those areas that had experienced flooding serious enough to warrant evacuation were more likely to have prepared 'flood evacuation plans'. Over half the EPOs who responded said that their areas had experienced serious enough flooding to warrant evacuation. Yet only 26% had detailed plans. Arguably, the existence of these more specific plans is as a result of a more reactive Emergency Management approach to the inception and preparation of plans, rather than a forward-looking proactive approach. However, in many instances institutional differences and the attitudes and approaches of individual EPOs across the regions may also be a considerable determinant.

This is particularly interesting when comparing flood evacuation plans with plans for other hazards. Whereas 39% of Emergency Planning Departments use technical data** and risk analysis, sometimes supplemented by use of maps, to define their areas at risk from "other" hazards (this includes CIMAH and PIRER sites), only 11% of Emergency Planning departments define their areas at risk from flooding in this way. Moreover, 42% of Emergency Planning departments determine the area at risk from flooding from the extent of previous events, compared to only 9% who do this for other hazards which may require evacuation. It could be argued, however, that historical data on flooding may be more readily available than for other hazards: the Seveso Directive which covers the obligation for public information and for local authorities to hold relevant information on serious chemical accidents (de Marchi, 1991) was passed in 1985, records before then may be incomplete.

The question that arises here is why should such a difference occur. Technical data is used for predicting areas at risk from "other" hazards, but not for areas at risk from flooding, although the technology** for obtaining this data clearly exists within the National Rivers Authority and other organisations (Parker et al, 1995), but is not fully taken advantage of by all Emergency Planning departments. Areas potentially at risk from flooding are more likely to be defined according to previous events rather than areas at risk from other hazards, even when the severity of the risk in question may be comparable or greater. The decision to use technical data to define area at risk is therefore not according to severity of risk.

Considering the lack of guidelines concerning the content of emergency plans***, one might expect to find considerable variability in detail and quality of the plans and the research evidence suggests that this is the case. Variability in content and detail of plans will undoubtedly influence the ensuing response, variability which may have to be accounted for at a national level.

Specific Evacuation Issues

We have collected information on many evacuation issues. For the purpose of this paper, three evacuation issues were chosen from our study, taken from recent literature (DoT 1994) to focus on the content of the relevant plans. These were whether the plan specified where the public should go for emergency accommodation; where they should go to board transport to emergency accommodation; and the route to be taken to drive safely out of a threatened area in their own vehicles.

The results showed wider variability than originally expected. Of the thirty-six County or Regional EPOs who said they had a plan which covered evacuation as a result of flooding, 73% of those plans specified where the public should go for emergency accommodation, 39% specified where they were to go to board transport, and only 20% stated what route should be used to leave the threatened area.

It should be pointed out that several Emergency Planning Officers felt that they had good reason not to cover one or more of these issues in their plans, usually because of the unpredictable nature and location of many disasters. The unpredictability of flooding is perhaps relative to some degree. Certain locations have flooded historically and information is available on approximate extent and recurrence interval. The National Rivers Authority is charged under Section 105 Water Resources Act 1991 (Subsequently outlined in MAFF-DOE Circular 30/92 Development and Flood Risk), to map the areal extent of flood risk for England and Wales and has much information available, although complete coverage at the national level is still a long way off. A number of floods occur, however, for which there is no available information and these are problematic for contingency planning.

** Technical data and technology with reference to flooding is taken as being weather radar, river gauges, telemetry, GIS etc.

*** This excludes rest centre plans, for which guidelines do exist

INVOLVEMENT IN PLANNING

Another issue evident in the US literature on evacuation regarding the development and implementation of evacuation plans, is that of whether those involved in carrying out the plan are in fact the same as those drawing up the plan: does the plan reflect the opinions and benefit from the expertise of all who are involved in an incident, for flooding or otherwise? Our research suggests that in general this problem has chiefly been addressed in the UK, although with some notable exceptions.

When drawing up the plan, the completed questionnaires showed that in most areas a wide range of officials, departments, voluntary agencies and individuals were consulted and invited to comment on the proposed plans. A distinction must be drawn between consultation and active involvement. The emphasis on consultation with the emergency services was quite marked. The police were by far the most frequently consulted body, followed by the emergency services as a whole and then the Fire and Ambulance Services. The Social Services department and the National Rivers Authority/River Purification Boards were also consulted in some cases (10% and 7%, respectively), as was the District or City Council. Local Authority departments which were specified included: Social Services (48%), Education (22%), Roads (11%), Environmental Health (8%), Water (7%) and Housing (4%). Other individual officials consulted in rare cases included Public Transport, Port Authority, Utilities, Industry and the Military.

The fact that only one Emergency Planning Officer consulted the Military was of particular interest, considering the, in some cases, strong role of the Military in recent serious flood events.

The Voluntary Agencies and individual residents consulted also showed a wide, and often imaginative, use of resources. The WRVS and British Red Cross were the most widely consulted of the voluntary agencies, 12% answered "voluntary services" as a whole. Other voluntary organisations included the amateur radio organisation - Raynet (10%), St Johns Ambulance (6%), the 4-wheel drive vehicle owners club (3%), the Salvation Army (3%), the counselling organisation - the Samaritans (2%), the Council of Churches (2%) and the Women's Institute (2%).

Local Residents Organisations and individuals were important consultees in a minority of cases, with retailers, Community Councils and resident representatives consulted. However, 14% of the Authorities admitted that they did not consult anyone other than officials and other departments.

When looking at which agencies and individuals are involved in putting the plan into action, it is of interest to us here to consider only those who were NOT reported to have been involved in drawing up the same plan, rather than list again every agency mentioned.

The evacuation centre/rest centre staff were amongst the few involved in the response phase of an incident, that is, in carrying out the emergency plan, but who were not consulted. Neither were organisations involved with the welfare and care of domestic animals. From past experience some local authorities have recognised that dealing with pets can be problematic during an evacuation and once the evacuation has been completed. Incidents have arisen where the refusal to leave pets behind during an evacuation or the problems caused by the presence of animals in rest centres has been an issue of some concern. Others involved in carrying out the plan, but not involved at the consultation stage were the Health Authority, the DHSS, Town Centre Security Staff, and interestingly the local media.

The media (including local radio, television or newspaper) has a dual role in emergencies in that they both report on an incident to a wider audience and pass on warnings and advice to a more targeted audience (Fordham, 1994). This is a role they play regardless of whether there is an evacuation or not, and a role that has been acknowledged both favourably and unfavourably on several occasions (Kelly et al, 1992; Braer oil spill 1993; Perth floods 1993, pers.comm.). It would therefore seem surprising that the media has not been invited at the planning stage to formally discuss how they might be used to best effect.

CONCLUSIONS

- Floods are infrequent events on a regional scale, but on a national scale this is not the case. Emergency Planning departments could, and should, take advantage of this in terms of cumulative lessons learnt.

- There exists a decentralised approach to emergency management in the UK: a system of regionally diverse roles, descriptions and expectations in the field of Emergency Planning. Despite this, better use should be made of the centralised information source and Home Office training centre in Easingwold and other information exchange opportunities.

- Lack of centralised government guidelines has resulted in a wide range of emergency plans in existence across the UK - Emergency plans covering evacuation for flooding are not comprehensive and are not prepared according to severity of flood risk. More importantly, emergency plans must not be seen to restrain flexibility: they serve a useful function in reducing error and promoting confidence in judgements.

- This lack of guidance leads to duplication of time, effort, resources and experience across the regions in the UK. This counters a principle objective of comprehensive and integrated emergency management.

- In most areas, a range of officials, departments, and voluntary agencies are consulted when drawing up emergency plans (principally the police and emergency services). However, consultation does not necessarily imply active involvement, and some involved in carrying out the evacuation were still not consulted/involved in drawing up the plan.

- Exclusion of the media from the consultation/drawing up stage of emergency plans appears to be inconsistent with comprehensive and integrated emergency management. Consultation with the media will optimize a dissemination process and mouthpiece, and in doing so, guarantee the media's co-operation.

- Predicting area under risk from flooding tends not to be calculated by use of technical data, instead there is an over-reliance on historical data.

Finally, it is encouraging to see the high response to our questionnaire, just one example of research in the Emergency Management field. An eighty-six percent response rate is notably high. However, what is particularly interesting is that 98% of respondents said they would be interested in participating in a follow-up study, many adding comments on other areas they felt could be covered in the future. Some even took inspiration from the questionnaire to follow-up particular issues in their areas. This response illustrates the interest and intention to learn and improve exists. The question being addressed is how to remove the barriers to this facility.

The authors would like to thank the UK emergency planning officers who answered the questionnaire and agreed to be involved in this study.

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Figure 1: Counties and Regions which were represented in the EUROflood questionnaire

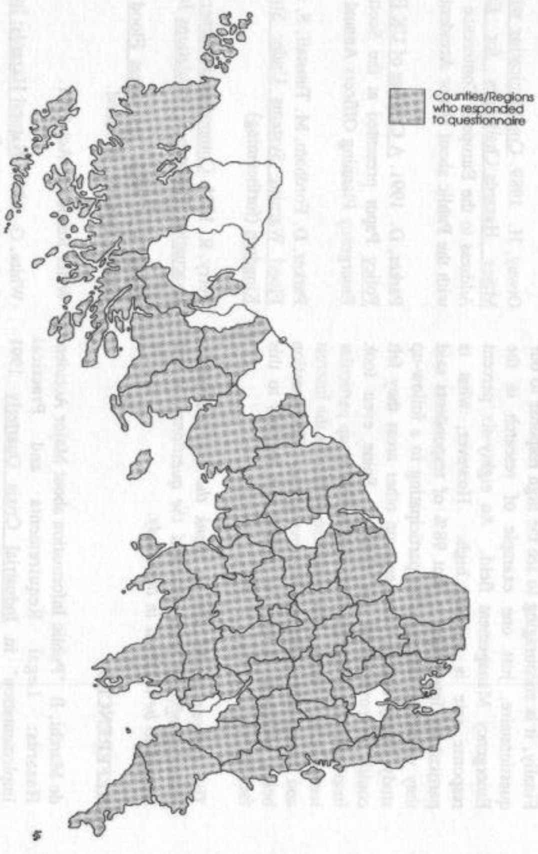
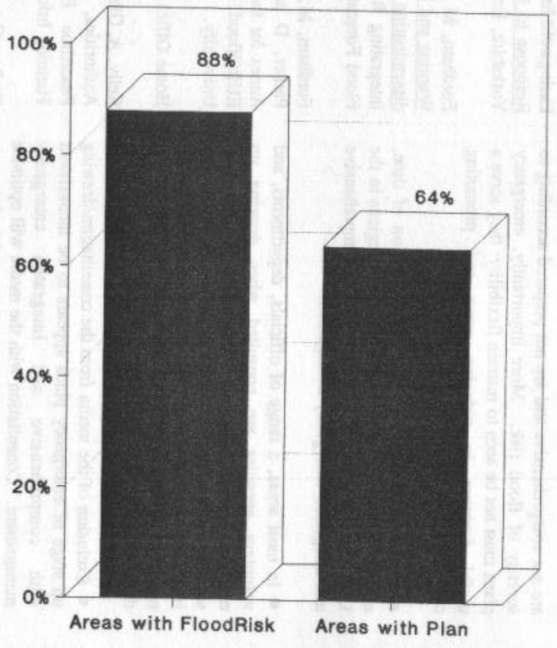


Figure 2: Flood risk and existence of plan covering evacuation for flooding



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THE ROLE OF RAINFALL RADAR DATA IN FLASH FLOOD ALERT

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KEYWORDS : flash flood, warning, alert, rainfall measurement, radar data.

ABSTRACT

In France, Flood Warning Agencies (Services d'Annonce des Crues or SACs) effectively monitor 16,000 km of water courses. But their mission essentially concentrated on reaches where flooding could be predicted and announced from rising waters in upper basins.

Following the catastrophic events caused by flash floods, mostly since 1988, there has been a demand for setting up warning units for small water courses or upstream of basins, that is, where a knowledge of precipitations is required if flood prediction is to be effective.

In this context, the only alternative seems a quantitative exploitation of radar rainfall data, however subject to several constraints. It should also be noted that a proper knowledge of rainfall is not a sufficient element : a chain of alert requires a quick successsion of actions from detection of a potentially dangerous situation to decisions on flood prevention and safety measures in the field. Nevertheless, there are still some areas where implementing a system of alert cannot be envisaged.

INTRODUCTION

In France, the 1988 disaster in Nîmes and repeated impressive and dramatic floods since 1992 (Vaison-la-Romaine) have made the general public aware of the risks related to intense precipitations and occupation of areas which can be flooded. A parliamentary committee was set up with an inquiry mission. It submitted a report in November 1994 (Mariani et al. 1994).

Thus, there is social pressure to limit the consequences of such events. This influences not only the evolution of measures and regulations concerning town planning, water course maintenance but also alert systems. In this respect, system limit and reliability are questioned. Indeed, a credible system must be capable of detecting with a minimum level of uncertainty (to avoid generating undue false alerts) any situation involving potential risks, anticipating the event as early as possible so as to give sufficient time for alert to be passed on to the sites concerned and for adequate protection measures to be taken locally.

In this context, for flash floods due to intense precipitations, the use of radar rainfall data is of prime interest. Existing alert systems could be extended upstream of certain catchment areas and additional means set up on new basins which have not been monitored so far.

The purpose of this paper is to set out the contribution of radar rainfall data to the system and how to make use of it in optimum conditions. After a brief reminder of some of the events which developed awareness in France, we will see the organization of flood alert and need for data on precipitations to implement a flash flood alert system before concluding on the contribution of radar to flash flood hazard prediction and prevention.

SINCE 1988, AN EVENTFUL HISTORY

On October 3rd, 1988, the city of Nîmes woke up under a storm and soon found itself invaded by torrential waters rushing down the hills surrounding it. The Cadereaux (generally dry thalwegs) discharged the runoff of a rain that had persisted for several hours with intensities of several tens of mm/hr. Cumulative rain depths exceeding 400 mm were measured.
Unfortunately, 9 people died and damage was valued at 4,100 million French Francs.

Violent storms hit the city of Narbonne in 1989, then the cities of Privas in 1990 and Orange in 1991. Each time, rainfall totals reaching nearly 300 mm in few hours were recorded. The geomorphologic conditions and the occupation of regions that had been hit limited the human consequences, however.

In September 1992, a Cévennes-type episode occurred again in the South of France with catastrophic human consequences in the départment of Ardèche (4 dead) and principally Vaucluse (37 dead, 29 of which at Vaison-la-Romaine and 5 people missing). One week later, the department of Aude was hit (3 dead, 5 missing). Overall, the disaster hit 718 boroughs with damage rising to FF 3,000 million.

In turn, both 1993 and 1994 saw a succession of very violent floods in small basins but also exceptionally high waters in the Rhône valley. During the summer and autumn 1993, 22 people were killed. Damage was estimated at FF 3,900 million, 1342 boroughs were affected.
During the 1993-94 winter, 2750 boroughs were inundated, 21 people died and damage has been estimated at FF 3,500 million.
1994 Summer and Autumn also brought about violent floods in the South of France (e.g., Nice airport flooding).

FLOOD ALERT ORGANIZATION

The state, although under no legal obligation to do so, has set up flood alert systems along 16 000 kms of water courses (out of 250 000 km) (Godard 1994). The main water courses are monitored and this covers the major part of the population exposed to the risk of inundation. There are 52 SACs in France (Flood Warning Agencies).

SACs are on the alert as soon as anticipated or detected rainfall exceeds set thresholds or water depths. They can track how the flood progresses through remote transmission of data logged by their measurement network and using modelling tools when possible (Godon, Odier 1994). When pre-set alert levels are exceeded, they contact the Prefect and suggest that he alerts the mayors of the boroughs since the mayors are responsible for the safety of populations over the territory of their boroughs.
Then, SACs keep the Prefect informed of the progress of the flood. Information is put at the mayors' disposal. This organization offers the advantage of centralized information at Prefect level, the alert resources (gendarmerie and national police) and rescue resources (firemen, civil defence) also being controlled by the Prefect. But it means that time elapses between the moment the information on the hydrologic situation is available to a SAC and the moment it is transmitted to the mayors and then to the populations. This is a limitation in the case of flash floods.
In addition, most SACs have been set up in basin parts having a sufficient response time to allow warning from the time upstream flooding starts propagating.
Thus, few basins subject to flash floods are monitored by a flood warning system set up by the state.

MONITORING MEANS FOR SMALL BASINS

Nonetheless, in some basins having fast response times (less than 10 hours in the south of France and in Finistère), the state did set up flood warning agencies. Some urban communities have also organized monitoring and alert systems on their territories (Nice for the Paillon basin, Marseille, Bordeaux and the départements surrounding Paris).

In all cases, the first step in situation monitoring resorts to the forecast broadcasted by Météo France. These forecasts extend from 12 hours to 3 - 5 days and cover surface areas of several thousand square kilometers. They are relatively qualitative.

The second step deals with the observation of data collected by the telemetering network of the alert agency : rainfall and runoff data. We note that there is a weakness in the system concerning the hours preceding the event, between the due date indicated in Meteo France forecast and the possible occurence of the event, if it occurs. This weakness is partly offset by satellite and radar observations. These qualitatively exploited images allow technicians to see in advance the coming disturbances (satellite images) and the precipitations (radar images).
With satellite images, you can follow a disturbance but you don't know exactly the precipitations it may cause. From the observation of radar images, the agencies can learn the times rainfall starts and finishes and have an indication on rainfall intensity and coverage.

Several agencies have hydrological rainfall-discharge conversion models at their disposal, which are activated after data collection. In these models, a major limitation is due to the quality of rainfall data inputs (LHF-EDF/DTG-RHEA, 1994). Indeed, generally, rainfall data are provided by rain gauges, which means punctual measurements and often daily accumulations.
An improvement is obtained by interpolating pluviographic data, at an hourly time step for instance. But rainfall can be so heterogeneous in space that during intense precipitations, errors in evaluating gross areal rainfall amount with a network of chart-recording rain gauges may exceed a factor of 5. And these errors are thus even bigger for net rainfall and runoff simulation results (figures 2 and 3).

REQUIREMENTS FOR INFORMATION ON PRECIPITATIONS

Summarily, intense precipations capable of producing flashfloods in catchment areas of up to 1000 sq. km can be divided into 2 categories (Roche et al. 1990) :

- local rainstorms of limited extension (some tens of sq. km) of short duration (up to one hour) and capable of dropping up to 100 mm of rainfall (figure 1),
- more extensive precipitating systems (several hundred sq. kilometres) persisting for several hours and of a variable intensity without being necessarily exceptional (some tens of mm/hr). Combined rainfall for such episodes may largely exceed 200 mm (figure 3).

During these episodes, the precipitations can be very heterogeneous. Thus, from many rainfall studies conducted by RHEA, values such as shown below and found on two typical rainfall events : that of July 18th, 1994 on Trappes radar (RHEA 1994) and that of September 22nd, 1992 on Nîmes radar (Kapfer 1993) have been obtained.

At the same time, the average intensity of precipitations over 1 sq. km can vary from a few mm/hr to over 120 mm/hr over a distance less than 2 km.
On one spot, the intensity factor can vary from 1 to 15 in 5 minutes (from 10 to 150 mm/hr). The accumulation of precipitations, for localized rainstorms can vary from 0 to over 80 mm over a distance of 3 km. For rainstorm systems, variation can range from less than 20 mm to over 200 mm over a 5 km distance.

The diameter of intense storm cell cores is a few kilometers long (rarely over 10 km). Typically, the trace of a rainstorm system accumulation exceeding 200 mm (Cévennes precipitations) on the ground is 25 to 50 km long and less than 10 km wide.

For catchment areas covering at least 30 to 50 sq. km, which could be equipped with an alert system (Tourasse 1992), it is therefore useful to know how rainfall is distributed in space with a 1 sq. km resolution. In fact, in the densest pluviographic networks, the rain gauge density is 1 for 10 sq. km in urban areas and 1 for 100 sq. km in rural areas.

The need for time data is twofold :

- The data discretization time step must be as fine as possible. It can be 1 min. for pluviographic data and 5 minutes for radar data. When the displacement of the rain cells exceeds 15 km/hr, it is useful to generate intermediate radar images by advection.
- The data acquisition time step must enable the user to apprehend the progress of the event as a whole but should not swamp him with data. In the SACs, the minimum time step for pluviographic data acquisition is 30 minutes because the extension of the area to be monitored and the application of the regulations on alerts and information generate tasks leaving little time for a more intensive exploitation of data. The desirable time step from a hydrological point of view is a 15-minutes time step.

A radar is a tool which can meet both conditions because its acquisition time step is 5 min. but it gives synthetized space information, very representative of the situation when images are animated and combined.
However, a radar makes an indirect reading of precipitations. Its data is to be calibrated. A conventional method is to corect them with the help of pluviographic data. Consequently, using radar rainfall data does not eliminate the need for operating a pluviographic network.

QUANTITATIVE EXPLOITATION OF RADAR IMAGES

Radar rainfall data is an indirect measurement of precipitations. In fact, it is the measurement of raindrop reflectivity in the volume scanned by the radar beam.
Raw data can therefore be fouled by errors due :

- to the measuring principle : "instantaneous" measurement of a continuous phenomenon and exploration of a volume represented by one value for 1 sq km : measurement of reflectivity related to the raindrop diameters to the power of 6, water volume being related to diameters to the power of 3,
- to the environment explored : heterogeneousness of the environment, 0° isotherm increasing the reflectivity, temperature gradient capable of modifying the linear propagation of the beam, obstacle creating interference clutter and masks,
- to the signal processing electronics.

The result expected by the hydrologists is a value for the areal rainfall of the precipitation. For a quantitative exploitation of radar rainfall data, it is thus essential to :

- minimize the risks of errors on raw data,
- correct raw data.

The hydrologic objective must therefore be one of the key elements when selecting the location of a radar. It is indispensable to be able to send out at a small site angle so that the beam does not rise too quickly. The area to be monitored must not be more than 90 to 100 km away. The French Ministry of the Environment has agreed to participate in Aramis network densification (Meteo France radar network) so as to allow a quantitative exploitation of radar data in the Mediterranean region. The measuring capability is one of the key factors for positioning radars (Comité Aramis 1995).

The conditions of radar exploitation must also integrate hydrologic requirements. They should tend to produce as steady a measurement as possible.
Various methods exist to quantify precipitations based on raw data. They are to be adapted as a function of the space-time scale desired by users and the problems they are faced with.
Calibration based on pluviographic data seems to be admitted by every one but the correction method can vary. Advection of images is however essential if you wish to compare radar and pluviographic rainfall data, above all for convective rains which generate flash floods.
As the basins to be monitored are often piémont zones (continuous alluvial cones), it is useful to deal with ground clutter. Mask processing can also be necessary.

All these processes show that raw radar information cannot be used without due consideration of meteorological and hydrological contexts. But for flash floods, rainfall measurement obtained by combining adapted radar data and pluviographic data is better than the existing (or even projected) pluviographic information in real time and at fine time steps.

THE CONTRIBUTION OF RADAR TO FLASH-FLOOD ALERTS

In a flash flood with consequences on human activity there is the existence of a risk and vulnerability. The risk will depend on the type of precipitation, the catchment area morphology, on the soil nature and plant cover... Vulnerability will be defined by the occupation of the ground and the nature of the activities created by this occupation.
To obtain an effective alert, all risk situations must be identified first. The contribution of radars will be, in differed time as in real time, to help identify the types of rain (Bressand, Kapfer, 1994).
In differed time, you can make use of case studies to analyze an event, work out a model and then make simulations.
A precise knowledge of precipitations sometimes helps to relativize, from a hydrological point of view, the most spectacular consequences of an event and refocus a hydrological analysis. This can be useful to improve the accuracy of models.
Thus on September 22nd, 1992, the heaviest precipitations in the Vaucluse departement did not occur upstream of Vaison-la-Romaine but farther South, in the Brégoux basin (Kapfer, 1993). The hydrological disorders observed on this basin are sometimes more impressive than at Vaison-la-Romaine (Gilard et al, 1993).

This analysis in differed time will then be used in real time to better predict the hydrological consequences of a precipitation.
A tool for exploiting rainfall radar data in combination with pluviographic data has been developed by RHEA. It is the Calamar system (from the French "CAlcul de LAMes d'eau à l'Aide du Radar" or radar calculation of areal rainfall).
Calamar has been adopted in several major communities (jointly by the Sanitation Authorities of 3 départements around Paris : Seine Saint-Denis, Val-de-Marne and Hauts-de-Seine, Sanitation Association of Paris Conurbation, Urban Communities of Bordeaux and Marseille) and the Flood Warning Agency of the department of Gard.

Each user has at his disposal a geographical data base describing the catchments basins areas to be monitored. For each of this catchment areas, the tool calculates the precipitations integrating the radar pixel values which apply to the areas. For the agencies, it means having on-line knowledge of the areal rainfall in each of the catchment areas through visualization of a rainfall hyetogram or rainfall accumulation chart starting from a given time (start of precipitation for instance). This result can also be transmitted to a rainfall-discharge simulation model (LHF-EDF/DTG-RHEA, 1994).
A prediction module for the areal rainfall in the next hour based on radar image extrapolation is also integrated in Calamar.

An exact knowledge of the precipitations on all the catchments areas monitored, updated every 5 minutes, enables a warning agency to anticipate on rain consequences : passing of alert thresholds (pre-determined by studies), identification of the situation with typical scenarios to which preset actions have been linked.

As a result, situations can be assessed in less time and with better precision and modeling and decision-aiding tools can be brought into play.
These resources should also enable a flood warning agency to integrate every risk situation as Calamar

contributes to an automatic, permanent "indefatigable" monitoring of situations and is a tool capable of generating hydrological alarms.

CONCLUSION

When the objective is to make flood warning toward upper basins more effective, and to extend this mission to basins subject to flash floods, the quantitative exploitation of radar rainfall data is a must.
This proved true for basins in the south of France using Nîmes radar.
Aramis radar network will be completed in the arc formed by the Mediterranean region. But this action should not stop here. Indeed, it is necessary to set up data processing and transmission means as well as operational tools capable of quantifying precipitations on catchment areas based on rain gauge and radar data.
Today such a tool exists, its is the Calamar system developed by RHEA.
It is also essential to set up teams to handle this data and operate the alert transmission chain.

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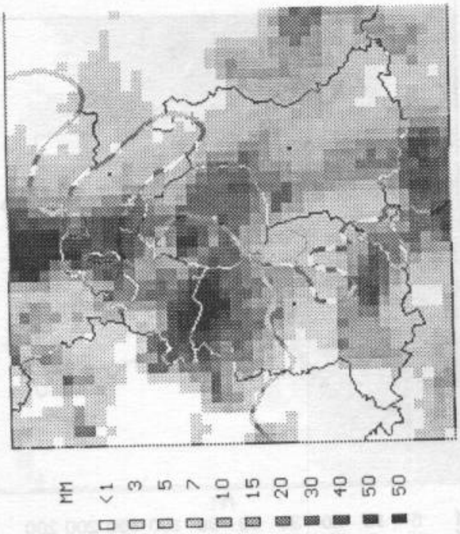

Figure 1 : Heterogeneousness of rainfall accumulation. Trappes radar (region of Paris), july 18th 1994 (1 pixel is 1 sq. km)

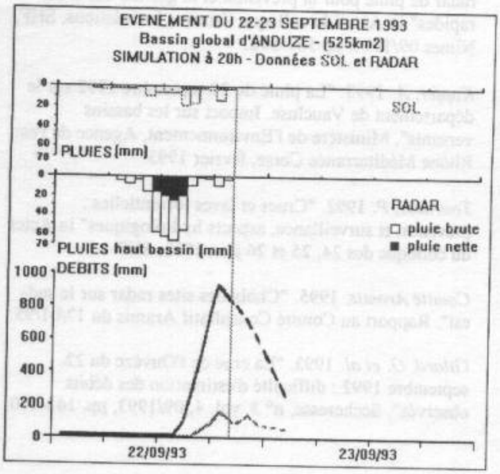

Figure 2 : Flow simulation for the subbasin of the Gardon d'Anduze river in the department of Gard (525 km²).

Comparison between raw and net rainfall from a nine rain gauges network (among which six are localised in the subbasin of the Gardon d'Anduze river) and from Nîmes radar data, september 22nd and 23rd, 1993. Result of a runoff simulation from the two types of rain data.

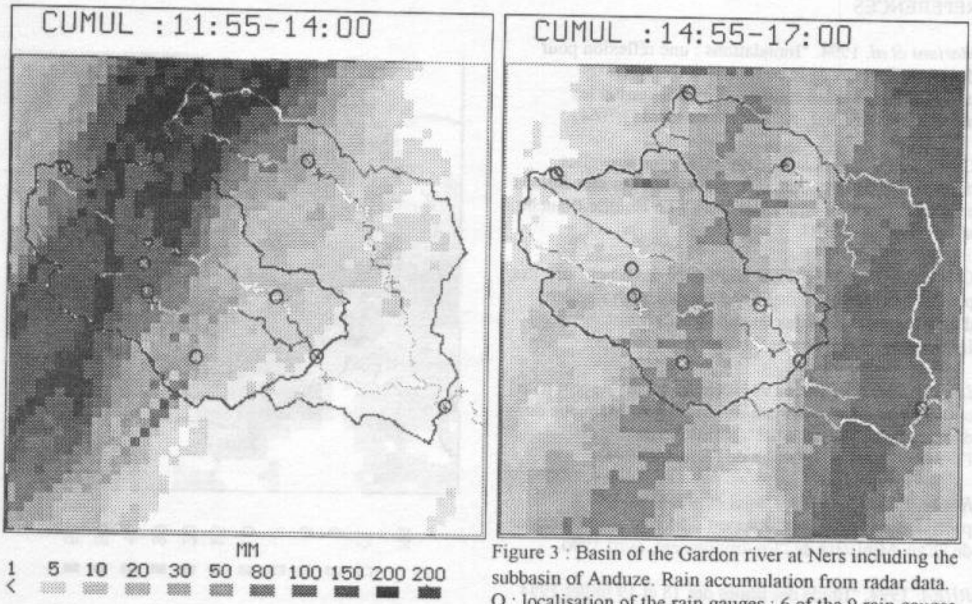

Figure 3 : Basin of the Gardon river at Ners including the subbasin of Anduze. Rain accumulation from radar data. O : localisation of the rain gauges : 6 of the 9 rain gauges are located in the subbasin of the Gardon d'Anduze river.

Calculation of extreme tidal sea levels based on nonlinear programming methods

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ABSTRACT

A numerical method is proposed for calculation of extreme tidal levels from the harmonic constants of any number of component waves with the aid of nonlinear programming. The method is applied on a computer for 34 component waves obtained from harmonic analysis of a monthly observation series by the Doodson method. The influence of the number of component waves considered on the extreme tidal levels is investigated.

1. INTRODUCTION

Information on extreme sea levels is needed for solution of various practical problems in marine navigation and hydraulic construction. On the tidal seas of Russia, where the mean tidal range (the difference between successive high- and low-water levels) is 50 cm or more, depths must be reduced to a theoretical zero depth (TZD). The theoretical zero depth is calculated by reducing the initial mean level by the amount of the largest tidal ebb amplitude that is astronomically possible, which is determined for each station from the harmonic constants. Many papers have been devoted to determination of extreme tide heights. The Laplace method is used for the particular case of regular semidiurnal tides [Vladimirskii 1941]. Until recently Vladimirskii method [Vladimirskii 1936] has been used in practical hydrographic and oceanographic studies to calculate extreme tide neights. In this method, the TZD is usually calculated from the harmonic constants of the eight principal components of the tide waves. Vladimirskii's method is extremely time-consuming. It does not take account of secondary tidal waves. Although their amplitudes are relatively small, they may, taken together, have a perceptible influence on the level.

In 1956, Kudryavtsev proposed a method for determining the TZD from the harmonic constants of the eight principal component waves of the tide. This is essentially a simplified Vladimirskii method. The author assumed that the tide waves with the highest amplitudes are also in phase. This assumption is quite artificial. The study [Peresypkin 1966], in which the extreme tide heights are calculated from the harmonic constants of 30 component tide waves, is similarly deficient.

It has recently become possible to use computers to solve the problem for any number of component waves. In 1974, Peresypkin proposed a method for finding extreme tide heights, which he developed in detail and used on a computer for 13 tide-wave components [Peresypkin 1974]. The method is based on solution of a system consisting of four equations with four unknowns. The deficiencies of this method include errors associated with the expansion in Taylor series and the poor convergence of the iterative process in the case of shoal waves with high amplitudes, which makes it necessary to carry out the solution in several steps.

2. NUMERICAL METHOD

The method proposed here differs from the above methods in that it is not subject to these shortcomings and uses simple computations that do not require a large computer memory. The method is developed and applied on a computer for 34 component tide waves. However, it can easily be extended to any number of waves, and an increase in the number of waves considered has no significant effect on the volume of a computational work. The problem is formulated as follows. The harmonic constants of the tide at some station are given. It is required to determine the highest and lowest levels that are theoretically astronomically possible at this station. The sea level H_t relative to mean sea level can, as we know, be represented in the form of a sum of tide waves:

$$H_t = \sum_{k=1}^{n} f_k H_k \cos\varphi_k ,$$

where for each wave f_k is a reduction factor that depends on the longitude N of the moon's ascending node, H_k is the amplitude harmonic constant, and φ_k is the phase of the tide component wave.

Harmonic analysis of tide observations consists in breaking up the composite wave into its individual components. Our problem is therefore to synthesize the component waves in such a way that the height of the tide assumes extreme values. According to [Vladimirskii 1941], it is necessary to shoose reduction-factor values that will give the largest effect for H_{min} and H_{max}. Reduction factors corresponding to N = 0° are chosen for the diurnal tides and values corresponding to N = 180° for the semidiurnal tides. In the case of mixed tides, the calculations are made in both ways and the largest absolute values are chosen. Our method is designed to use initial data in the form of results of harmonic analysis of monthly series of observations by the Doodson method, which can be made to yield the harmonic constants of 34 waves. Calculations that consider larger numbers of secondary waves with amplitudes in the centimeters and fractions of a centimeter do not promise any significant improvement. This becomes understandable when it is remembered that the absolute variations of the harmonic constants of the main waves exceed the harmonic constants of some of the secondary waves.

The values of the reduction factors for the cases N = 0° and N = 180° and the expressions for the phases as functions of the principal astronomical elements of the 34 component tide waves (2 long-period, 10 diurnal, 10 semidiurnal, 12 shallow-water) are chosen from [Peresypkin 1966], where t is the mean civil time reckoned from midnight, h is the mean longitude of the sun, s is the mean longitude of the moon, p is the mean longitude of lunar perigee. The rest of fundamental astronomical elements have the following periods, during which they assume all possible values from 0 to 360°: t = 24 mean hours, s = 27,3 mean days, h = 365,25 mean days, p = 8,85 years, N = 18,63 years. Since the periods are not commensurable with one another, we can, over an indefinitely long span of time, obtain simultaneous combinations of all combinations of values of t, s, h and p, while N can assume the constant values 0 and 180°. The astronomical conditions are determined from the following criteria: $s - h \approx 0°$ at new moon, $s - h \approx 180°$ at full moon, $s - p \approx 0°$ at perigee, $s \approx 0°$ (or 180°) for the moon on the equator, $s \approx 90°$ for the greatest northern declination of the moon, and $s \approx 270°$ for the greatest southern declination of the moon.

For simplicity in the exposition that follows, we introduce new notation, namaly: we shall denote a function by ψ and the argument corresponding to it by a vector x

$$x = (x^{(1)}, x^{(2)}, x^{(3)}, x^{(4)}) = \\ = (t, h, s, p).$$

In the new notation, the problem can be formulated thus:

$$\min(\max) \psi(x) = \\ = \min(\max) \sum_{k=1}^{34} f_k H_k \cos \varphi_k. \quad (1)$$

The problem (1) is a problem of nonlinear programming. At this time, one of the most widely used methods for finding the extremes of a function is the gradient method with its various modifications. This method is simple and makes possible complete solution of the problem in many cases. However, it has a highly important shortcoming: it can be used to find only local extremes of a function. In practice, this difficulty can be overcome by preliminary investigation of the function and subsequent comparison of the results obtained. We propose here an extreme-search method that combines the method of sequential enumeration and the method of steepest descent.

Let the function $\psi(x)$ be defined on a compact set

$$X \in E_4,\ E_4 = \{x^{(1)}, x^{(2)}, x^{(3)}, x^{(4)}\},$$

where E_4 is a four-dimensional Euclidean space. The maximum of the function $\psi(x)$ on X is reached on a certain nonempty set $S \subset X$. We note first of all that $\psi(x)$ is continuous on E_4 and 2π periodic with respect to each argument, i.e., $X \in [0, 2\pi]$. We denote the solution of this problem by $F(x_{*})$. It is necessary to determine $F(x_1)$, the extreme of the function of four variables, with a predetermined error ε and to find the point x_1 at which this approximation is satisfied:

$$F(x_*) - F(x_1) < \varepsilon.$$

The problems of finding the lowest and highest levels are solved similarly. For consistency, we introduce the symbol

$$L = \begin{cases} 1, \text{if } \max\psi(x) \text{ is sought}, \\ -1, \text{if } \min\psi(x) \text{ is sought}. \end{cases}$$

The object of the search is to find a combination of values of the arguments x at which the value of the function $\psi(x)$ is at maximum (by introducing the symbol L, we have reduced the extreme-search problem to a maximum-search problem).

The numerical solution of Eq. (1) is carried out in two steps. In the first step of the extreme-level search, a discrete minimax problem is solved to find the initial approximation. We vary successively only the first coordinate of the vector x with the other arguments fixed, assuming

$$x_1^{(1)} = 0,\ x_2^{(1)} = x_1^{(1)} + C_1, \ldots,$$
$$x_n^{(1)} = x_{n-1}^{1} + C_1,$$

where C_1 is a certain increment (const). We find F_n from the formula

$$F_n = L \max\,[L\psi(x_1), L\psi(x_2), \ldots, L\psi(x_n)]. \qquad (2)$$

If we have obtained $x_n^{(1)} > 2\pi$ after the n-th step, the level calculations at this step are terminated, with the result that F_n assumes the maximum value. In the case of semidiurnal tides, when the largest tides are observed at new moon and full moon, the values of the other three coordinates in the calculations with (2) can be put equal to 180° (new moon, perigee), while in the case of diurnal tides, when the highest tides are observed at the greatest declinations of the moon, the values of the other three coordinates are taken equal to 90° (greatest northern declination, perigee). The choice of these initial values of x_o, for which $\psi(x_0)$ is near the extreme, and the use of the enumeration procedure for the first coordinate eliminate unpromising local extremes from consideration. In determination of the lowest level of an irregular semidiurnal tide, for example, the sequential enumeration method enables us to find low water springs, and then it is precisely this level that is subsequently minimized (improved).

We fix the value of the vector x_n, which corresponds to F_n, and go on to the second step of the search, in which the method of steepest descent is used with double the change in increment [Evtushenko 1971]. Let us illustrate the working principle of the method in this case. We take the step

$$\tilde{x}_1 = x_n + \tau_1 L \nabla \psi(x_n).$$

There $\tau_1 > 0$ is a coefficient and $\nabla\psi$ is the gradient of the function ψ, i.e., a four-dimensional vector with the coordinates $(\partial\psi/\partial x^{(1)}, \partial\psi/\partial x^{(2)}, \partial\psi/\partial x^{(3)}, \partial\psi/\partial x^{(4)})$. The gradient $\nabla\psi$ indicates the direction of steepest ascent (descent) of the function in the neighborhood of a given point. For the point x_* to be an extreme point of $\psi(x)$, it is necessary that the equality $\nabla\psi(x_*) = 0$ be satisfied. The magnitude of each i-th coordinate of the gradient vector of $\psi(x)$ is evaluated from the formula

$$\frac{\partial\psi}{\partial x^{(i)}} = \frac{\psi(\tilde{x}) - \psi(x)}{\Delta x};$$

here $\tilde{x}^{(j)} = x^{(j)}$ for all $j \neq i$ and $\tilde{x}^{(i)} = x^{(i)} + \Delta x$ for $j = i$.

If the condition

$$L(\psi(\tilde{x}_i) - \psi(x_n)) > 0 \qquad (3)$$

is satisfied at the step i = 1, we take $\tau_2 = 2\tau_1$ and make a second step:

$$\tilde{x}_2 = \tilde{x}_1 + \tau_2 L \nabla\psi(\tilde{x}_1),$$

and so forth until condition (3) is satisfied. If condition (3) is violated at a certain i-th step, we take

$$\tilde{x}_i = \tilde{x}_{i-1} + L\,\frac{\tau_{i-1}}{4}\,\nabla\psi(\tilde{x}_{i-1}).$$

The optimum step length is chosen in this way. The iterations are terminated if the condition

$$|\nabla\psi(x_i)| < C_2,$$

where C_2 is a coefficient, is violated. Thus, the search process reduces to determination of the most promising regions, in which the method of steepest descent is then used to find the value of the function $F(x_i)$ with the required accuracy.

The program generates the extreme value F, which represents the largest deviation from mean level, as well as the values of the astronomical arguments t, h, s, p, and N that correspond to the extreme. The value of t determines the mean civil time, and the value of h the day and month. These data can be used for calculations of the values of s and p at 0^h on 1 January, and then the tables of the astronomical elements can be consulted to determine the year in which the extreme tide level may occur for the particular station.

3. THE INFLUENCE OF THE TIDE COMPONENT WAVES

Table
Extreme Levels (cm)
as Functions of Number
of Waves Considered

No of waves	Ekaterininskaya Gavan		Kem	
	H_{min}	H_{max}	H_{min}	H_{max}
8	− 203	196	− 98	97
13	− 198	202	− 92	111
25	− 209	213	− 89	108
34	− 209	214	− 90	111

Table presents values computed from 8, 13, 25, and 34 component waves for the extreme tidal levels at the Ekaterininskaya Gavan and Kem stations (White Sea). The group of thirteen waves included, in addition to the eight fundamentals, the three shallow-water waves M_4, MS_4, and M_6, which are most often taken into account in computation of extreme heights, and the two long-period waves Mm and Msf. In the calculation using 25 component waves, the thirteen waves, named above were supplemented by the remaining semidiurnal and diurnal waves. The data in Table indicate that the positions of the extreme levels are adjusted as the number of secondary waves is increased, and that calculations based on 25 and 34 component waves give closely similar results. The largest difference between the values of the extreme tidal levels obtained from 8 and 34 component waves is 18 cm for Ekaterininskaya Gavan and 14 cm for Kem at high water springs. Thus, the additional waves, from the ninth on, change the results of the extreme-level determination significantly. Consequently, the proposed method makes it possible to improve the accuracy of the calculation and can be used for practical purposes.

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THE DESIGN AND MANAGEMENT OF AN INTERNATIONAL DISASTER INFORMATION RESOURCE NETWORK
[BUILDING AN EMERGENCY LANE ON THE INFORMATION SUPERHIGHWAY]

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"In today's new world order, information serves as an empowerment tool that can assist a nation's pursuit of sustainable development by diffusing useful information to citizens, businesses, and research institutions."

ALBERT GORE, U.S. VICE PRESIDENT

Although hazards are unavoidable, the disasters that sometimes accompany natural and technological events may be. While some countries have a remarkably good capacity for coping with hazards, from time to time even the most technologically advanced need help from their neighbors. It is necessary, wise, and efficient for those concerned with emergency management to establish a worldwide network of information systems related to hazard management, so that disasters do not arise as a result of an emergency situation. One thing that can be done is to improve the quality and quantity of hazard related information so that international, national, regional, and local emergency readiness and response can be effectively deployed in real and near-real-time.

Such a network will enable the emergency management community to work together as a "virtual community", drawing on each other's resources as needed. Instead of costing additional resources, it is hoped that this holistic approach to global emergency management will reduce overall resource requirements by encouraging cooperation.

In order for all emergency managers to be empowered with the capabilities this network can yield, the system must be scalable; that is, able to support interactions with users of varying levels of technology. One important goal of such a network is to simplify an emergency manager's search for information from many sources and its efforts to compare information that is presently given at different scales and uses different terminology. To be successful, information needs to be broken down into manageable units and the units prioritized according to need and utility.

Ongoing improvements in telecommunications and the application of common technical standards along with computer technology are making it possible to generate and/or gather information at an unprecedented rate, distribute it instantly around the world, and through its analysis and application create new products, services and businesses. New and improved communication and information technology opens opportunities for initiating improvements in integrating and coordinating information across disciplines and across national and international jurisdictions.

New forms of networking depart from traditional centralization of information and place greater emphasis on information exchange as the central function. Information on a particular subject is no longer being placed in central depositories, but rather elements are stored in computers all over the world to be assembled into a larger picture through network links. Information exchange, organized through networking, forms the cohesion for this virtual community.

In order for the emergency management community in this new information based virtual community to further hazard management programs, (including all characteristics - hazard and risk assessment, prevention, preparedness, warnings, response, recovery and rehabilitation) all participants must make information sharing a primary goal. This requires the hazard management community to first recognize the paramount importance of information exchange as a pivotal part of information management and then to acknowledge the supportive role that networks play in such activities.

Beyond this, there is a critical need to raise awareness among information system and network developers that their facilities represent important resources needed in the global exchange to mitigate disasters.

The worldwide network of computers called the Internet would be a reasonable framework upon which to build this emergency management network. Offering such advantages as a well-understood protocol and global coverage, the Internet is a logical choice.

In addition to offering global coverage, the Internet is a valuable asset to the emergency management community because it accesses a wide variety of emergency management information sources. For example, in addition to information providing organizations such a Volunteers In Technical Assistance (VITA), the National Center for Earthquake Engineering Research (NCEER), etc., many of the Governmental and non-governmental organizations involved in emergency management operate on the Internet already.

In order to be of maximum value to the emergency management community, this system must be designed with "scalability" and global access as central themes. Thus we envision that such a system will include Internet based servers with several alternative interfaces in order to support a wide variety of user capabilities. This combination will provide access for users regardless of whether they are using sophisticated computer machinery or simple systems composed of little more than a terminal and a modem.

This system would become a conduit for providing and exchanging critical emergency information between representatives in a stricken area, the U.N., governmental, and non-governmental organizations (NGOs) involved in disaster relief. An Internet based emergency management system including pre-hazard training and warning capabilities, combined with real-time field reporting capability has the potential to save vast amounts of human life and property.

One of the other capabilities a world-wide network provides is the ability to send warnings of potential natural hazards to the population in an affected area, as well as to the media who will use their capabilities to reach even more people.

In summary, the Internet including such systems as HazardNet provide the world-wide emergency management community with unprecedented tools for the mitigation, and response to natural and technological disasters. Efforts are under way to develop systems that will utilize this tool to its fullest potential. Before the end of this decade we will see Internet based emergency management begin to achieve this goal.

There have been several prototypical systems developed in efforts to harness the Internet. The first of which is EPIX, Emergency Preparedness and Information Exchange. EPIX was based on a series of text menus available via an information search and retrieval mechanism called "gopher".

Later, DRIX (Disaster Reduction Information Exchange) was developed to provide access to information on disaster prevention, mitigation, and preparedness. Information provided through DRIX was intended to assist in policy formulation and planning, statistics gathering, research and awareness-raising to increase knowledge about and strengthen capacities for disaster prevention, mitigation and preparedness. DRIX contained links to servers maintained by many government and private organizations, such as those identified above.

FIRRE (Facility for International Readiness and Response to Emergencies). The focus of FIRRE was on providing access to information for use in "monitoring, early warning, and alert of possible, incipient or ongoing emergencies and natural disasters, and for the purpose of preparing, facilitating, conducting and coordinating effective and timely international response." FIRRE contained computer links to databases about "Current Emergency Situations" (including disaster situation reports compiled by Volunteers in Technical Assistance), "Humanitarian assistance" (including a wide range of information about refugees, human rights, emergency relief statistics and supplies, and relief organizations), "Daily News Bulletins and Current Affairs", "Country-Specific Information" (including country profiles from the U.S. State Department and the CIA World

Factbook, maps from the World Map Collection at the University of Texas and the Canadian National Atlas Information Service), "Natural Hazards" (including current weather maps and satellite images), and "Monitoring Programmes" (such as the World Food Programme Food Aid Monitor).

A third prototype which brought all of these capabilities together was developed under the auspices of Project IERRIS (International Emergency Reduction, Readiness/Response Information System). The IERRIS prototype employed advanced telecommunications and computer technologies to provide a single entry point to databases of public and private disaster mitigation and relief agencies throughout the world. Also, this prototype provided a blueprint of a data structure that ties field reporting, warnings, and relief status reporting into a coherent whole.

As stated in the IERRIS Project Abstract:

The Project [was] to enable the actors concerned to: adopt information management procedures that are of common benefit; to work with common and/or compatible information management standards and technologies; collaborate in the development of new information systems and procedures so, as to meet information needs that are not met by existing systems and procedures, and to share and exchange suitable emergency-related information collected for respective institutional needs. This concerted effort will result in major improvements in the quality, specificity and timeliness of information available internationally for early warning monitoring reporting, resource mobilization, and coordination, evaluation, disaster reduction, and the information exchange, reference and referral services related to all these concerns.

Presently, an operational system is being developed (in cooperation with the U.S. National Weather Service and California Office of Emergency Services) on a test-bed and development platform located at the Centre for Policy, Research on Science and Technology at Simon Fraser University. This operational system is called HazardNet. HazardNet draws together the ideas and design from all of these prototype systems and has synthesized them into a single system.

HazardNet is intended to be a global, all hazards network tying together all elements of emergency management before, during and after an event occurs and providing the nexus for governments and NGOs to interoperate and mitigate disasters arising from natural and technological hazards. This shall include enhancing the timeliness, quality, quantity, specificity and accessibility of information (including real-time warnings of all-hazards) for persons and organizations world-wide concerned with preventing, mitigating, preparing for or responding to large-scale natural and technological emergencies.

Work on this project is on-going. It is hoped that the system will be demonstrated and evaluated widely by the emergency management community. To access HazardNet from the World Wide Web, go to: "http://hoshi.cic.sfu.ca/~hazard/

TIEMEC '95

NUCLEAR HAZARDS

TIEMEC '95

Nuclear Emergency Systems

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INFORMATION SYSTEM AS TECHNICAL SUPPORT FOR THE MANAGEMENT OF NUCLEAR EMERGENCIES

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ABSTRACT

Following to the Chernobyl accident, that affected large europen areas, many countries have improved their organisations for the management of radiological emergencies, in order to make them suitable to face situations with a large territorial impact in terms of contamination.

In case of accidents with a deep radiological impact, the national competent authority has the role to make decisions about countermeasures to be adopted in order to minimize the consequences of the contamination to population and to the environment. Such countermeasures get adopted on the basis of measured contamination as well as on the basis of the forecast evolution of the radioactive plume.

In order to accomplish this role, it is necessary to have, in real time, the availability of all the relevant information required to assess and to continuously update the accidental scenario as well as the possibility to perform forecast about the evolution of the situation.

To this purpose ANPA Emergency Centre has designed and implemented an Information System in Support to Nuclear Emergencies Management (SISGEN) which is rapid and reliable in the acquisition and elaboration of huge quantities of data.

This paper presents data elaborated by the information system as well as objectives, functions and architecture of the system.

INTRODUCTION

A nuclear emergency is a very particular situation which get started whenever there is a risk of contamination and irradiation to the environment and to population due to accidental releases of radioactive material (i.e. accident to a nuclear power plant).

In Italy, during an emergency a committee of expertise's, named CEVaD, is activated to follow and estimate the evolution of the accident and its radiological impact and to make decisions based on the radiological scenario about eventual countermeasures (evacuation, sheltering, etc.) depending on the accident, in order to limitate damages to population and to the environment (Di marco G."et al." 1994).

This committee is under the Department of Civil Protection and the technical support is supplied by the Emergency Center of the National Agency for Environmental Protection (ANPA).

According to this role, the Emergency Center has developed an information system (SISGEN) that acquires, elaborates and supplies in real time to the expertises all the information needed to manage properly and quickly an emergency (ARA/CEM 1991).

The main objective of the system, that acts as a technical support in case of emergencies, is to supply:
- a correct evaluation of the radiological impact following a nuclear accident to population and environment;
- a forecast about the evolution of contamination and sanitary impact,

in order to take proper countermeasures for the protection of population and environment following a nuclear accident with a deep radiological impact on national territory (Ursino S."et al" 1993).

The estimates and forecast are based on data described in chapter Data managed by system of the present paper.

Data collected in real time during an emergency are stored into databases and made available, together with previously acquired data, to CEVaD for consulting and elaboration by means of interactive and automatic functions described in chapter Functions of the system.

SISGEN is a modular distributed system having various functions loaded on different dedicated and properly configured hubs of a local network, and various data stored on different databases which are reachable from all interested hubs. The system integrates different operative systems (VMS, DOS and UNIX) and employs a GIS (ARC/INFO) and a X-Window user interface whose architecture is described in chapter Architecture.

Chapter Conclusion, describes advantages and future development of the system that have been pointed out during operative tests of the system.

DATA MANAGED BY THE SYSTEM

Data managed by the system may be grouped into the following four categories:

- notification data collected in real time from national and international authorities;
- radiometric data measured in real time by laboratories spread all over national territory;
- meteorological data, both measured and forecast, supplied by National Meteorological Office;
- territorial data, already available at Emergency Center, which remain unchanged during emergency.

Notification data are information about the accident that are contained in the notification messages, and concern location of the release, date and time of release and other relevant information about the accidental scenario which are available when the notification message is sent.

These data come from the plant where the accident took place and, usually they arrive by telephone or by fax in plain language. Anyway, according to conventions with IAEA and CEC the member State where the accident happened must inform IAEA and/or CEC and send them all the information available in a coded form by means of telex or the GTS (Global Telecommunication System, that is the W.M.O. world wide network) for dissemination to all the other member States. This information are the first to be available and play a key role for the activation of emergency.

Radiometric data are information about radioactive measurements performed by laboratories (or mobile units) spread all over national territory according to five different kind of measurements: irradiation, air concentration, ground concentration, wet and dry deposition (fall out), concentration of nuclides in foodstuff.

Measurement data are contained in predefined forms filled by laboratories and sent in real time to the Emergency Center by fax. The measurements give the concentration on main radionuclides (I131, Cs137, etc.) in air, on the ground and in the main foods. All the measurements are connected to other data like date, hour of sampling and location of sampling. These data allow to report in real time the radiological scenario and to provide data required to perform estimates of doses to population.

Meteorological data are collected and sent through the GTS by national and international meteorological stations. These data are available at the Emergency Center by a direct link with the National Meteorological Office, that is a hub of GTS. The most relevant information are: wind speed and direction, precipitation and cloud coverage, and forecast field data issued by the European Center for Medium Range Weather Forecast.

These data allow to assess in real time the meteorological scenario above the area involved or to forecast by means of dispersion models the trajectory of the radioactive plume in the atmosphere and the locations where deposition is most likely to take place. This is relevant in order to make decisions about the areas where proper countermeasures must be adopted.

Territorial data are already available at the Emergency Center and remain unchanged during a nuclear emergency. These data are relevant in order to locate exactly the accidental scenario and its evolution in order to decide the proper countermeasures to protect population (evacuation, sheltering, iodine tablets distribution, etc.).

In the last years ANPA has collected a lot of territorial data about all national territory. In particular, databases have been developed containing most relevant data for emergencies management as:

- communications (railways, roads, etc.) to be prepared to face eventual evacuation;

- land use, to take eventual countermeasures involving foods (vegetables, fruits, meat, milk);
- hydrography (Guarracino M. and Seart s.p.a. 1990), to study the evolution of contamination in water bodies;
- orography (Ursino S. 1991), to make accurate dispersion forecasts and for a morphological knowledge of the area ;
- administrative boundaries (national, regional, provincial and municipal) in order to connect data to location of reference;
- demographic data (number of inhabitants, age classes, etc.) relevant in order to give information about the number of people living inside contaminated areas;
- location of measurement laboratories with all related information (address, telephone, kind of available measurement devices, etc.).

Most of these data have been retreived from Army Geographical Institute cartography (scale 1:250.000). Great efforts are being devoted to obtain more detailed information (scale 1:25.000) as far as municipalities data are concerned.

Furthermore, ANPA Emergency Center has the availability of cartographic data all over Europe at scale 1:1.000.000 about most relevant information with particulate attention to location of meteorological stations and nuclear power plants.

The effectiveness in supporting decision makers depends on the ability of the system to acquire in real time data which may change during an emergency (radiometric and meteorological), to elaborate and integrate them with territorial data and to give the experts a continuous monitoring of the situation at national and local scale.

FUNCTIONS OF THE SYSTEM

During an emergency data collected in real-time are stored into databases, and made available, together with previously acquired data, to CEVaD for consulting and elaboration by means of interactive and automatic functions. All these functions have been grouped, during the designing of the System, into five classes: Acquisition, Automatic elaboration, Interactive elaboration, Consulting and Management.

Acquisition consists of hardware and software resources for acquisition, validation and storage of notification, radiometric and meteorological data collected in real time.

In particular, meteorological and coded notification data are acquired automatically by the computer, while radiometric data and non coded notification data must be inserted manually into the computer. Radiometric data are stored according to computer procedures that direct and validate the inserting data process (Di Marco G. "et al."1992).

Automatic elaboration consists of batch procedures performing calculations and reports to summarize the radiometric scenario and its sanitary impact on population (Di Marco G. "et al."1992).

The radiometric scenario is presented by means of following procedures:
- daily production of tables where, for each region, statistics about contamination on environmental matrixes and foodstuffs is reported (list of measurements, average value, minimum, maximum, standard deviation);
- continuous displaying of irradiation measurements updated for each italian municipality (more than 8.000 italian municipalities);
- displaying of average values, for each region and for eventual areas of interest, of air and ground concentration for two selected nuclides.

The sanitary impact on population is presented by means of daily production of tables, where, for each region, doses to population are reported. Contribution of each nuclide to daily dose as well as total dose are calculated from radiometric measurements data, averaged for each region, and employing dose factors that take under consideration, for each nuclide, different age classes and different pathway of exposure. Furthermore, cumulated doses over a given number of days of exposure are calculated.

Total doses are relevant to make decisions about countermeasures like evacuation and/or sheltering, partial contribution to total dose are relevant to make decisions about specific countermeasures like iodioprophilaxis or foodstuff banning.

All these data are stored into a database of the system and are available for further consulting options.

Interactive elaboration consists of software models and procedures that allow the user, on request, to perform further elaboration on acquired data.

The user may ask for calculation of averages or doses for particular days, areas of interest, nuclides and matrixes.

Results are displayed and printed but they are not stored in the system.

Furthermore, the user has the availability of tools to evaluate in real time the meteorological scenario above the area involved (METEODATA) (Picodata s.r.l. 1991) and to forecast the trajectory of the radioactive plume in the atmosphere as well as the location where deposition is most likely to take place (ARIES) (Desiato F. "et al." 1993). Finally, a model for the estimate of long term contamination in foodstuffs and projected doses to population due to different pathways of exposure, is also available (EURALERT) (Muller H. "et al." 1989). This model takes under consideration the evolution of contamination in the environment, the radioactive decay and population diet.

Consulting consists of software procedures for retreiving, correlating, and reporting acquired and elaborated data stored in the system.

The retrieving and reporting actions are performed by computer procedures directing the user to specify data required both acquired (notification, radiometric, meteorological) and elaborated (statistics on contamination, doses, plume trajectories and meteorological fields).

The correlation and reporting actions are performed by means of Geographical Information System (GIS) (Ursino S. "et al." 1992) allowing production of thematic maps. In particular procedures have been developed to allow:

- making an interactive inquiry of radiometric, demographic, meteorological, territorial data of a particular area or location;
- supplying a graphic output of dispersion models as far as the trajectory of the radioactive plume over the territory is concerned;
- supplying a graphic output of meteorological data;
- reporting information about national laboratories, national and european meteorological stations, and european nuclear power plants.

Management consists of additional functions, allowing the user to set proper parameters into the system to take under consideration the evolution of the situation. The user may define regions, areas, radionuclides, foodstuffs, diets and age classes for the automatic elaboration previously described. Furthermore, the user ask for plots of time evolution of the contamination for each region.

In addition, the system is comprehensive of procedures to update dose factors and to customize meteorological data acquisition scheduled queries.

Finally, by means of GIS is has been possible to develop procedures to select interactively new areas of interest in addition to regions, to produce geographic maps for items of interest in order to properly locate notification, meteorological, radiometric and dose data as well as trajectory of the radioactive plume.

ARCHITECTURE

SISGEN design has been started in the beginning of 1991, following to the design of a radiometric data management system, and with the aim of integrating data managed by this system with other data managed by software products already available. The implementation of the system required a GIS (ARC/INFO) for the development of procedures for the correlation of radiometric, notification and meteorological data with territorial data.

The implementation of the radiometric data management system was carried out at the beginning of 1992 and this system became operative at the beginning of 1993, after one year of tests and drills.

Up to now SISGEN is comprehensive of: a system that collects all the functions for radiometric data management (SIGEDRA), a system for notification data management (SIPRON), a system for radioactive plume trajectory forecast (ARIES), a system for projected doses evaluation (EURALERT), a system for meteorological data management (METEODATA) and a system for territorial data management (GIS). Fig.1 shows the Data Flow Diagram for this situation and underlines the flows of data from sources to users.

Most of the functions and data of the system are managed by a computerised distributed system constituted by a local network (ETHERNET) connecting two computers (VAX 6000- Digital) in cluster, a Workstation (DEC Station 5000/240), a PC (DEC Station 325) and an interface for remote connections apart from a lot of peripherals for inserting, printing and displaying data.

Hardware and software architecture of the system has been realized in such a way that all network hubs are organized as a specialized work station in order to accomplish specific functions and able to have access to all the data stored in the system.

The software products are modular and run on different operative systems (VMS, DOS and UNIX); they employ ARC/INFO procedures for territorial data management and X-Window as user interface.

SIGEDRA run on VAX in VMS environment and its software is constituted by FORTRAN programs and/or DCL commands, radiometric and dose data are stored into relational databases (RDB); SQL embedded language has been employed as Data Management System.

The peculiarity of this system is the ability to insert, validate and store a huge quantity of data, by means of masks directing and validating manual inserting procedure and by means of the development of two relational databases.

SIPRON runs on PC in DOS environment, the software is constituted by a package for coding and decoding notification messages and has been distributed by IAEA and CEC to all member states, on request. This product has the ability of catching coded notification messages sent by telex and/or GTS; this capability has been realized by means of a telex and a GTS interfaces which are able to recognize messages from a keyword identifying this kind of messages.

ARIES runs on VAX computers in VMS environment and is constituted by FORTRAN programs and DCL commands. The system contains modules which are able to forecast the trajectory of a radioactive plume on the basis of physical models from data about the accident and meteorological data.

METEODATA runs on VAX computers in VMS environment and contains FORTRAN programs and DCL commands. This system is able to acquire and store in real time data collected from meteorological stations all over the world and disseminated by GTS. This has been realized by means of a dedicated connection with the Meteorological Service and by procedures for acquisition and storage of data.

GIS runs on Workstation in UNIX environment; the software is constituted by ARC/INFO commands and AML procedures. This system has the ability of managing many different territorial items by means of ARC/INFO peculiarities and by means of several databases collecting territorial data that may be relevant for the management of a nuclear emergency.

CONCLUSIONS

The present paper has briefly described the organization that has been predisposed in Italy for the management of nuclear emergencies and the role of ANPA Emergency Center in this contest. Furthermore, the information system developed to provide required technical support to decision makers has been presented.

In particular, functional and operational characteristics of the system have been presented underlying performances and goals like , for example, the ability of the system to manage in real time all the information needed during an emergency and the employment of a GIS to correlate and georeference of data stored in the system.

Tests and drills demonstrated that SYSGEN allows the user to have detailed and standardized information in a users friendly way in order to get in real time an ergonomic estimate of the accidental scenario on the territory.

As far as further development is concern, it has been planned to implement a computerized system for automatic acquisition and storage of radiometric measurements performed by laboratories spread all over national territory; and to load Client-Server network protocols that will improve the abililty of the system to exchange data among the different work stations. With a longer period of time it has been planned to load SIGEDRA, ARIES, METEODATA and another GIS on two different Workstations (Alpha-Digital) in OPEN-VMS environment resulting in a great improvement of computer time consuming.

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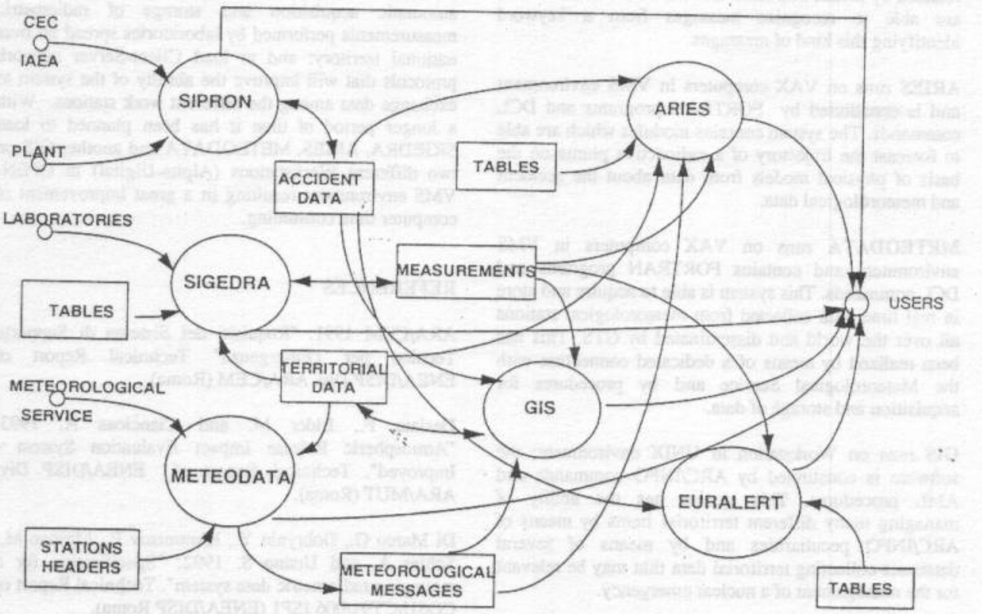
FIG 1

DATA FLOW DIAGRAM OF SISGEN



INTEGRATING PLANT-INTERNAL AND PLANT-EXTERNAL INFORMATION SYSTEMS FOR OPTIMAL HANDLING OF NUCLEAR EMERGENCIES

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KEYWORDS

Decision support systems, system integration, nuclear emergency management, information integration.

ABSTRACT

The handling of nuclear emergencies is a complex task, which may involve rescue personnel at the emergency site as well as personnel residing at significant distance from the disaster area. This paper will focus on integration of support systems for use in emergencies arising from nuclear power plant accidents and will cover both plant-internal and plant-external aspects.

The different decision centres being involved in management of nuclear accidents, the plant control room, the technical support centre and the regional and national emergency centres, are briefly described and focus is placed on the utilisation of a common information base, containing basic information being presented at an inter-centre level. The utilisation of advanced information systems for decision support as well as national emergency management systems is discussed in an attempt to optimise their use in an integrated information network.

1. INTRODUCTION

The accident at the Chernobyl Nuclear Power Plant in the USSR in 1986 clearly showed that nuclear emergencies may constitute a severe threat to modern society. It became obvious that such accidents not only would have impact on the plant itself and its local surrounding area, but could influence territories on a national as well as an international scale. This paper will not focus on the security aspects of different kinds of Nuclear Power Plants, NPP, or discuss relative probabilities for accidents to happen within specific plants. However, we know that accidents do happen and in this paper we will try to identify how management of serious nuclear emergencies may be made more efficient by integrating support systems.

The handling of major nuclear emergencies is an extremely complex task and will involve personnel located at the different decision centres, both within the NPP facility and on a regional and national basis. The involved personnel at each centre will have their own information base available as support for their decisions and mitigation strategies. Problems arise when the basis for decision at one decision centre is incompatible with that of another, therefore it is essential that the information base provides consistent and up-to-date information.

The heterogeneity of information needed at the different decision centres is obvious, however, some key information is required at all centres in order to present a complete overview of the situation. The required level of detailed information varies, especially regarding power plant operation parameters. Such parameters are widely available in the NPP control room, while other decision centres could utilise a condensed set of such parameters. To be able to utilise this information as part of their information base, it is important that the parameters are continuously updated via specific network facilities. One can also anticipate that off-plant decision centres could derive considerable benefit from high-level expert knowledge generated on-line by advanced expert systems, as well as key results from predictive simulations based on the current situation.

This paper will concentrate upon describing the different decision centres being involved in managing serious nuclear accidents and try to identify how information can be shared between the different centres in an optimal way. Nuclear power plant operator support systems for advanced information integration and accident management will be identified as potential systems for managing the required information exchange and being the source for intelligent information generation. A national emergency management system for handling nuclear emergencies, being developed under the Eureka umbrella, will also be presented as one source of information in the total nuclear emergency management information network.

In some countries the integration of information is well under way. This is, however, not the case for other countries, where there is a lot to achieve by introducing a common information network.

2. EMERGENCY MANAGEMENT DECISION CENTRES

NPP Control Room

Two categories of staff work in the control room: operators and shift leaders. Their responsibility is to handle the plant in normal situations, in situations with disturbances, and in situations which may turn into an accident. In more serious situations they will have to ask assistance from people in the Technical Support Centre, which will then be manned. The more serious the situation, the more of the responsibility is transferred to the Technical Support Centre.

There are large amounts of information available in the control room, typically thousands of readings from instruments in the plant: temperatures, pressures, water levels, valve positions etc. Some of the most important physical quantities may be measured by several instruments.

Based on a complex information pattern the staff shall try to form a mental picture of what is going on in the plant. This is no easy task, especially in an abnormal situation. For example, it is not easy to see the difference between a fault in a component like a valve or a tank and an instrument error. And if the present state is correctly understood, what will now happen? Will the trouble calm down, or will it develop from bad to worse? What counteractions should I do?

The control room staff may benefit from several types of assistance :

- signal validation
- status identification
- diagnosis
- presentation of higher-level information than just measured quantities
- prediction of what will happen if nothing is done, or if a proposed counteraction is carried out
- generation of strategies
- implementation of strategies

The immediate concern of the control room staff is the situation within the plant, external conditions should influence its work only if there is a direct cause-consequence relationship.

NPP Technical Support Centre

A nuclear power plant usually has several reactors, each with its own control room. In addition, there is a technical support centre that is common to all reactors of the plant. The technical support centre is usually located in an underground bunker, and it is not manned under normal circumstances. In an emergency situation the centre is manned, its staff comes from the plant management and from the staff of those reactors that are not in trouble. The staff of the technical support centre will make an independent assessment of the plant situation and give advice to the control room of the impaired plant. In this function they will concentrate on the broad lines and leave the details to the control room. Moreover, the technical support centre will coordinate the fire brigade, will take decisions (in cooperation with the police and other local authorities) on whether to evacuate the local population or not, and similar questions. It will also furnish the press centre with information.

To function, the technical support centre will need plant-internal as well as plant-external data. The centre will also need to communicate with the staff at other centres, like the control room, the police, the press centre, the fire brigade (of the plant as well as that of the local community), the hospital, and the regional emergency centre.

In addition to plant-internal data (pressures, temperatures, radioactive release, or the risk of radioactive release) the technical support centre will also need plant-external data like information about meteorological conditions, the measurements of local radiation monitors, static demographical information, and dynamic demographical information (for instance, is there a football match at the stadium in the wind direction).

Regional Emergency Centre

In the event of an accident with emission of radioactive materials outside the plant perimetry, the regional authorities are in most cases responsible for initiating the required measures. To protect the public from adverse health effects and secondly minimize the economic impact of the accident, the county commissioner's staff must have access to information that covers most aspects of crisis management. Information on the source or installation causing the pollution is naturally of prime importance, and direct contact to the supervisory system at the plant would be useful. However, the county authorities are not in need of any detailed technical information, but rather an easily understandable picture of the present situation at the source, the amount of radioactive materials released and the projected releases. To obtain this knowledge at the earliest possible moment is essential for efficient handling of a nuclear emergency. Decisions on countermeasures such as intake of iodine, sheltering or evacuation has to be taken early on in the course of an accident, and even though the time saved may be counted in hours or less, the dose averted may be considerable. Thus there should be a direct line of contact between the technical support centre and the regional centre, with transmission from the installation to the centre of select information on plant status, measures initiated or planned and projected development. From the centre to the scene of the accident there is a counterflow of information on the authorities' handling of the situation and the impact this has on the actions taken at the site.

The complex interplay between accident site or utility, the regional emergency operating centre, police, civil defence and the public is difficult to handle even with the aid of an efficient communication and information presentation system. The flow of technical data, messages and commands demands a large capacity network, but equally important is the ability of the computer system to select, condense and present information to the decision makers [Kvalem, 1994]. A unified approach to all these activities is necessary to ensure that all staff involved in emergency handling are presented with a correlated and comprehensive view of the course of the accident, mitigating measures and the cooperation with the public.

National Emergency Centre

A large release of radioactive materials may have serious consequences far outside the site of origin, and to protect life and property in such cases is a national responsibility. The tasks of a national emergency centre are determined by considerations that are partly different from those that dominate the in-plant and local activities. Knowledge of technical matters or local conditions is not essential, what matters is existing and predicted releases, how much is expected to reach national territory, if the accident takes place in a neighbouring nation, and what will be the probable radiological impact. This information is necessary input for the actual decision process which has to take several other conditions and constraints into account. The overall effectiveness of measures is not a simple question of comparing doses to the population with, versus without sheltering, evacuation etc., and then try to maximise averted dose. Any mitigating measure involves a set of actions that disrupt normal life and has its economical and psychological costs. To arrive at a balanced view the decision makers at the national emergency centre require access to a broad information spectrum :

- present and predicted status at the source
- updated global meteorological charts with air currents and precipitation patterns
- weather forecasts on a national level and predicted concentration of radioactivity
- population affected and dose distribution without countermeasures
- dose averted by various countermeasures related to their practical execution
- short and long term health effects
- economical consequences and environmental impact

In addition there should be continuous monitoring of progress in accident mitigation and resource allocations, not to mention the need for timely and precise information to the public and media. Many problems arising during and after an accident could have been avoided by keeping the public well informed and suppress the speculations and psychological strain that are fairly certain to follow in the wake of a major nuclear accident.

3. INFORMATION NEEDS

As described in the previous chapter the decision centres have different needs for information, based on their specific work tasks. To get a comprehensive overview of the situation each decision centre needs data originating from other cooperative decision centres. Figure 1 tries to illustrate the integrational aspects being addressed in this paper, by identifying the four relevant decision centres and their requirements for data and information. The thickness of arrows in the figure depicts the volume of information flow.

The data requirements indicated in Figure 1 are described below.

Plant Data

All plant-internal data (measurement data as well as data derived from measurements) are available in the control room. A selection of plant data are needed in the technical support centre. A regional emergency centre will need a narrower selection, and a national emergency centre quite few plant data.

Local Data

All relevant local plant-external data (demographical, meteorological, radiological, etc.) available in the technical support centre, less in the regional emergency centre, even less in the national emergency centre.

Regional Data

All relevant regional plant-external data (demographical, meteorological, radiological, etc.) available in the regional emergency centre, less in the national emergency centre and in the technical support centre.

National Data

All relevant national plant-external data (demographical, meteorological, radiological, etc.) available in the national emergency centre, less in the regional emergency centre.

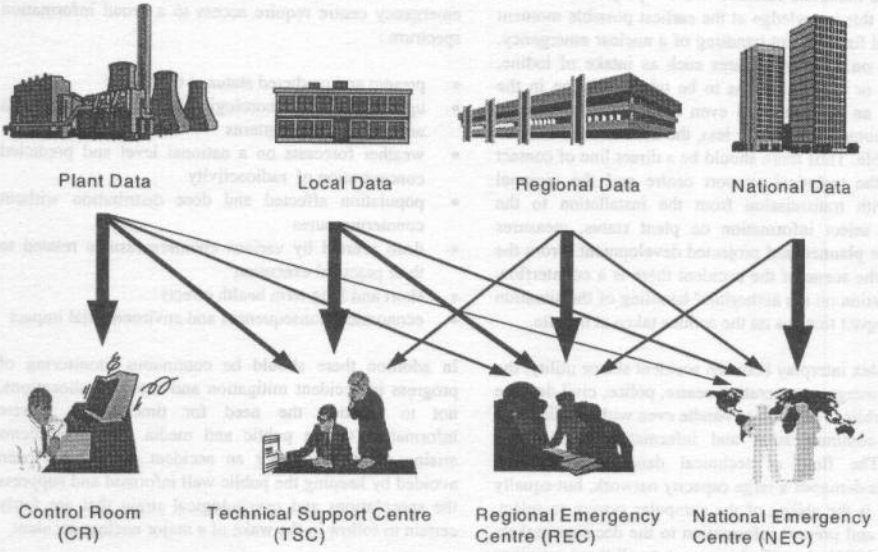

Figure 1 : Information flow

4. COMMON INFORMATION PLATFORM

In a previous chapter the decision centres involved in handling nuclear emergencies have been described. The information required at the centres differ according to their personnel's specific work tasks, however, the need for a common information platform seems obvious. Computerised information systems aiding personnel in their specific work tasks should exist as parts of the information basis at all centres involved in emergency management. Several decision supports systems are even integrated at specific centres to obtain a comprehensive overview of the situation. However, the inter-centre integration of information is normally not operating the same way, resulting in lack of a common information basis for sound decisions to be taken across decision centres. How should one then obtain such an inter-centre integration? One way is to take advantage of already existing support systems residing at the different centres and see whether it is possible to extend their scope to operate on an inter-centre basis. Several decision support systems for accident management and information integration have been and are currently being developed within the Halden Reactor Project and principles applied in their design may be used as basis for integration.

CAMS

The Computerized Accident Management Support, CAMS, is a system that will provide support concerning the plant operation in normal states as well as in accident states [Fantoni, 1994]. Support is offered in identification of the plant state, in assessment of the future development of plant conditions, and in planning of mitigation strategies. The system picks up information from the plant and transforms it into a more digestible form before presenting it to the users. The transformation process can be controlled by the user. CAMS is restricted to plant-internal parameters and plant-internal operations. It consists of a signal-validation module, a tracking simulator, a predictive simulator, a strategy generator and a critical function monitor. At the present time, CAMS exists as a prototype to test out the possibilities of the chosen design, and is still under development.

ISACS

The Integrated Surveillance And Control System, ISACS, is a general concept for advanced control rooms, in which emphasis is put on efficient use of modern computer technology to help solve problems in many of today's control rooms. Major points are the need for a careful integration of a number of specific operator support systems, with respect to information integration, software and hardware aspects and the design of the man-machine interface [Haugset, 1992]. The "heart" of the ISACS concept is the Intelligent Coordinator, which continuously supervises information coming from the different operator support systems. The information is used for analysis of the status of the plant and the Intelligent Coordinator can activate support systems for acquiring additional diagnosis or prognosis. The Intelligent Coordinator then generates high-level information for the operator and presents the information through a fully unified man-machine interface. A first prototype of ISACS is currently in operation in the research laboratory at the Halden Project.

MEMbrain

The Eureka project MEMbrain (MEM: Major Emergency Management) is centred around the development of modules tailored to applications in MEM systems, included handling of nuclear disasters [Drager, 1994]. It aims at providing the information acquisition and processing functions together with communication modules that are needed in emergency management. It is mainly directed towards use in the handling of accidents on the national or regional scale, but may at a later stage encompass all levels involved in a nuclear emergency, integrating the in-plant information system with external systems that are designed for national or regional emergency centres.

Personnel being involved in major emergency management on an extended geographical scale will require meteorological information, access to short and long distance dispersion models, geographical information systems including detailed demographical information for the threatened area, and extensive communication facilities for contact with supporting institutions as well as local and global preparedness organisations. All these aspects are being covered as part of the MEMbrain concept currently under development.

Aspects Of System Integration

The decision support systems described above have their traditional origin as indicated in Figure 2. However, they can most probably meet the requirements indicated by the thin lines of Figure 1, by extending their ability to supply the decision centres with data originating in another centre. CAMS and ISACS will typically provide information from left to right in Figure 1, based on their origin as control room systems. MEMbrain, however,

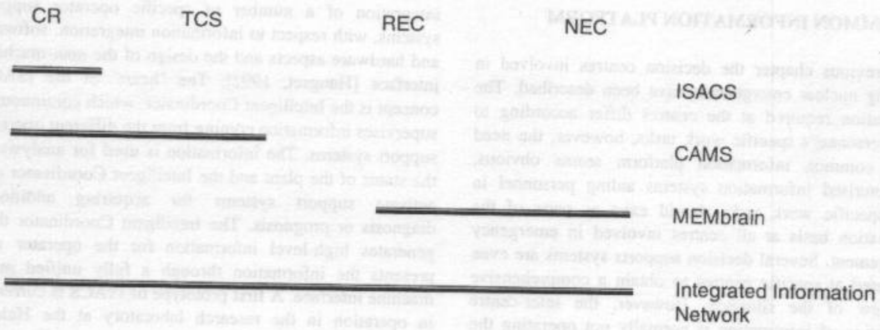

Figure 2: Distribution of systems across centres

with its main functionality directed towards national emergency management, should typically be extended to act as an information provider from right to left in Figure 1.

To introduce several free standing support systems, although they are partially integrated, does not produce a complete information network. An overall coordinating system is required, collecting and distributing relevant information to and from several sources, refer Figure 2. The ideas behind the ISACS Intelligent Coordinator concept, which until now has been implemented on a local scale, i.e. for the control room, may possibly be utilised to meet requirements of a totally integrated information network on a broader scale :

- collection of relevant information, provided for instance by single systems like ISACS, CAMS and MEMbrain
- condensation of collected information
- prioritisation of information relevant for each specific centre
- intelligent decision making
- generation of high-level information
- proposal of actions/mitigation strategies
- intelligent person-to-person communication facilities
- intelligent distribution of information

The functional requirements described above will put severe demands to the technical solution for such a computerised system. An efficient data communication network, with the utilisation of wide area networking and satellite communication facilities, is one of the key factors for such a system to function properly. Efficient database and expert system management are other factors which will require careful consideration before implementation.

However, we believe that there exist mature information technology solutions today, which can make it possible to build an integrated information network for managing nuclear emergencies. Such an information network can be based upon existing support systems already implemented and utilisation of ideas that have already proved their worth in smaller scale environments.

5. CONCLUSIONS

The goal of the ideas presented within this paper is to provide decision makers handling nuclear emergencies with the best possible information basis for making their decisions. Computerised information systems exist and although they have been developed for different purposes and different tasks, an extension of their scope making them serve additional purposes is definitely possible. In such a way it should be possible to integrate different support systems across decision centres providing personnel with an extended and common information basis, which could assist them in functioning even better in executing the complex tasks of nuclear emergency management.

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ETH - RISKMONITOR: LINKING PLANT ON - LINE MONITORING TO RULE - BASED ASSESSMENT AND EMERGENCY PLANNING FOR NUCLEAR ACCIDENTS

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Abstract:
The ETH-RISKMONITOR is a DSS designed to assist real case on-line remote monitoring of nuclear power plants for abnormal event categorizing based on plant condition, and its evolvement, issuing of recommended alert grades, prompt determination of endangered / exposed sectors in a territory and on dose and health effects maping. It is an application on linking plant on-line monitoring to rule-based assessment and emergency planning for nuclear accidents.

INTRODUCTION

The Polyproject " Risk and Safety of Technical Systems", an interdisciplinary research project undertaken by the Swiss Federal Institute of Technology (ETH) -Zürich aims at providing a coherent framework for critical, comparative evaluation and development of methods and practical tools in risk analysis and safety management of complex technical systems, the operations nature and scale of which may entail health and environmental hazards. The nuclear risk assessemnt and safety management issues have found a natural place within the above project.

One central result of this approach was ETH-RISK (Gheorghe et. al.,1994)-an early intervention-oriented software package meant as a component in Decision Support System (DSS), GIS based/oriented dealing with emergency preparedness and management, and later performing integrating functions such as:

1) - anamneses of experts and decidents, in order to infer from the **natural languages;** statements, the nature of abnormal events in nuclear power plants;

2) - abnormal event categorizing based on plant condition, and its evolvement;

3) - issuing of recommended **alert grades** (e.g. Warning, General Alert, Radiation Alert);

4) - prompt determination of endangered or otherwise exposed sectors in the territory; and of the cantons falling within the incidence of these;

5) - definition of **accident source terms**;

6) - probabilistic / deterministic environmental dispersion scenarious;

7) - dose and health **effects mapping**;

8) - complex mapping of zones of recommended **countermeasures** (sheltering, administration of stable iodine tablets, evacuation, relocation);

9) - filling reports to relevant **emergency management** authorities.

AN INTEGRATIVE APPROACH

As a feedback received from exercising with ETH-RISK (e.g. from nuclear regulatory bodies, from NPP operators, etc.), a shorthand version primarely assembling the functions 2, 3, 4, and 7 in the aforementioned enumerationed was designed. ETH-RISKMONITOR is the code name for the result of an exercise to meet the respective propositions. ETH-RISKMONITOR is an expeditious software facility designed for the on-line supervising by authorized agencies, of the operational status of the nuclear power units in Switzerland. ETH-RISKMONITOR was developed as a research exercise within Polyproject "Risk and Safety of Technical Systems" at the Swiss Federal Institute of Technology ETH -Zürich. In essence, this DSS simulates a dynamic, on-line updated data-base coupled to an alert and fast consequence assessment facilities via a rule base system. The code modules:

i) perform a synoptic, or a parameter-by-parameter monitoring of the operating of the nuclear power units (e.g. Beznau-blocks 1 and 2-, Leibstadt, Goesgen, and Muehleberg);

ii) signal and record departures of the monitored parameters - pressures, temperatures, levels / concentrations, dose rates in critically important parts of the system-from the normal / acceptable operational ranges of variation;

iii) correlate inacceptable departures from normality to alert grades, based on the legally enforced criteria, procedures and practices in Switzerland;

iv) upon a very minimal input, including e.g. the NPP location, prevailing wind direction, general type of weather (with high / low consequences), severity of the accident in comparison to the Swiss reference accident, and assumed degree of sheltering of the potentially exposed population, provide a fast-if rough-preliminary evaluation of the expected consequences of the abnormality, should a release effectively occur.

Three modules would emboy the functions above:

- MONITOR.GEN, which concentrates the **database and monitoring functions;**

- MONITOR.RUL linking abnormal occurences to alert grades via **accepted rules**;- ALERT that incorporates **accident consequence assessment** procedures.

Within the monitoring mode the user may wish to keep the code into displaying the on-line reported values of all the parameters of a given NPP unit. A shorthand synoptic table, a list of full-name parameters and their values, or "topical" lists-of all parameters of the pressure / temperature / level etc. type can be displayed and watched as these vary in time. Alternatively, each and every parameter can be put on display, together with its full description (index, measuring point at the plant, measuring units, etc.), and current value. The existing softwate allows the user to make changes as far as the description of the parameters, altering e.g. their names, indexes, characteristic value etc., or to add new parameters to the list of those already monitored, or to delete some parameters from the lists.

The general organization of the information is "vectorial"; each file contains one variety of information: name of parameters to be monitored, their index in the power plant documents; denomination of the measuring points, physical units, the most expected value in normal plant operation, and six significant limits of variation (attention, critical, accident, upper and lower levels) - 11 species altogether.

OFF-LINE AND ON-LINE REGIMES

There are two regimes into the monitoring mode of the code; off-line, and on-line, with reference to the data transmission from the nuclear installations targeted for monitoring. To simulate an accident, while in the on-line data transmission regime, a series of instructions are available through the menue of the code. Once the code operator is out of any doubt that the departure of the plant parameters from their routinely expected values signals an accident with offsite consequences, one may activate the facts-to-alert- grades module of the code.

The current version of the code offers an interim solution to the problem. Pending a satisfactory definition of a comprehensive set of rules linking various combinations of (Level 1) plant condition parameters departing from their respective ranges of normality, on the one hand, and the legally enforced alerting grades in Switzerland i.e. **Warning, General Alert, Radiation Alert**; on the other hand, a minimal set of alternative / complementary facts is used instead, to quantify the alert grade via regulatory rules.

As conceived, the rules are simple **logical operations OR and AND** that are performed on facts such as various managers propositions or decisions, the condition of some components (e.g. emergency cooling pumps), the values of some (actually, only a few) plant control parameters etc. and amounting to one of the alert grades. The algorithm and coding would therefore reflect these, inevitably introducing precautions of the type "insufficient information", or "check this information" for contradictions. In the context, "information" means the set of assumptions on what facts occured and concurred in the abnormal event in question. A pointer is made available to the user, to select (combinations of) facts. The code will make it a rule to always take up the worst alert grade that may emerge from the user-chosen combination of facts. Such an approach would stress expert judgement against the sought automation of the analysis and assessment process, which however is believed to be only a transient difficulty.

In operating this code sequence the user is requested to carefully examine the inventory of facts in display, and then point to one or several of these, as indicated by the monitoring process and/or resulting from other insights. A visual expression of the rules articulating the facts and linking the logical result to a certain alert grade will then be displayed for examination. If unsatisfied with the outcome, the user may repeat the process.

At this point it is to be remainded that, as all components or spin-offs of the ETH-RISK system, ETH-RISKMONITOR abides by a policy of advising the emergency manager, yet never deciding instead of him (her). A visual expression of the rules articulating the facts and linking the **logical results** to a certain alert grade will then be displayed for examination.

ACCIDENT CONSEQUENCES

Once the alert grade established, a series of graphic helps will be activated, and on-line helps and prompts will lead the user through a series of procedures that would materialize in a shorthand sort of fashion the current Swiss dose concept.

In broad lines, the user:

- will use a cursor to select and point at the NPP location on the Switzerland's map;
- will set the dominant wind's direction (using arrow keys) and will watch as the code will draw the 120 deg. angle around this, marking the endangered and exposed sectors into the territory, as defined by the Swiss legally enforced procedures;
- will assign missions to the emergency officers, confirming to the code the accomplishments of the various phases into the mission;
- will match as the code will identify the cantons falling within the incidence of the endangered / exposed sectors - and where, consequently, adoption of alert / action station is expected.

This phase consummated, further steps into the consequence assessment may be undertaken. Thus, upon giving his best guess on how the current accident relates to the Swiss reference accident as descriebed in (HSK, 1991) and what kind of weather prevails ("'weather with high consequences" or "'weather with low consequences"- to use the Swiss official language), the user will be promptly given the zones where various health effects are to be expected, including the positionning of the zones on relevant maps of the territory surrounding the nuclear units in question. Also the radial distribution of doses into the territory taking into account assumed degrees of shelterring (outdoor, indoor staying, in-cellar, in-shelter) can be rendered on maps.

All the results as descriebed express the **"legal truth"** in the procedural documents guiding the emergency preparedness and management in Switzerland; in particular dose maping relies on the dose vs. distance curves. This approach was thought in tune with a regulatory body practice, although it does not preclude the use of more elaborate accident consequence analysis tools. ETH-RISKMONITOR has been written for the IBM PC family. It is less demanding that ETH-RISK in terms of hardware performance. Any system beginning with the 286 series will do. However, given the association of ETH-RISKMONITOR to ETH-RISK, the standard requirements for the latter, i.e. a 33 MHz or higher clock, a 8 MB RAM, and an EGA or VGA graphic adapter and color monitor are recommended.

ON-LINE FACILITIES

Whenever at runtime, one may:

- save a graphic screen as recoverable bitmap;
- print a text (ASCII) hardcopy of the screen.

CONCLUSIONS

The ETH-RISKMONITOR is an expeditious software facility designed for the on-line supervising by authorized agencies, of the operational status of the nuclear power units in Switzerland. This software was developed as a research exercise within Polyproject "Risk and Safety of Technical Systems", at the ETH-Zürich.

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A SPECIAL PURPOSE VEHICLE FOR RADIOLOGICAL EMERGENCY RESPONSE

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ABSTRACT

The scope of this paper encompasses the design and application of a Contamination Control Station (CCS) Response Vehicle. The vehicle is part of emergency response assets at the Department of Energy Pantex Plant, the nation's final assembly and disassembly point for nuclear weapons. The CCS Response Vehicle was designed to satisfy the need for a rapid deployment of equipment for the setup of a Contamination Control Station. This deployment may be either on the Pantex Plant site, or, if directed by the DOE Albuquerque Operations Office, to any location in the U.S. or worldwide to a site having radioactive contamination and needing response assets of this type. Based on the specialized nature of the vehicle and its mission, certain design criteria must be considered. The vehicle must be air transportable. This criteria alone poses size, weight, and material restrictions due to the transporting aircraft and temperature/pressure variations. This paper first focuses on the overall mission of the vehicle, then highlights some of the design considerations.

SCOPE

The scope of this paper encompasses the design and application of a Contamination Control Station (CCS) Response Vehicle. The vehicle was designed to support the Radiological Assistance Team at the Department of Energy Pantex Plant, the nation's final assembly and disassembly point for nuclear weapons.

BACKGROUND

Pantex Plant

The Pantex Plant, located about 18 miles northeast of downtown Amarillo, Texas, is managed and operated by Mason & Hanger- Silas Mason Co., Inc. The U.S. Department of Energy directs the operations of the facility and the approximately 3,100 workers employed at the site. The primary mission of Pantex is the assembly and disassembly of nuclear weapons. Secondary missions include the processing of high-explosives and mock-explosive components, interim storage of plutonium "pits", and the assembly of weapon-like devices for testing and training programs.[1]

Radiological Assistance Team (RAT)

The Pantex Radiological Assistance Team (RAT), consisting of approximately 70 responders, maintains capabilities to perform offsite and onsite monitoring and assessment as directed by the DOE Regional Coordinating Office in Albuquerque, NM. In addition, the RAT is responsive to the Department of Defense, Department of Energy, and Federal Emergency Management Agency (FEMA) tripartite agreement to support each other for world-wide response to nuclear weapons accidents. These capabilities must be flexible enough to support response throughout the full range of peacetime nuclear accidents offsite, to include those involving nuclear weapons, nuclear power reactors, transportation of radioactive materials, and nuclear medicine.[2]

In support of the above mentioned potential accidents, the RAT is trained to conduct several response activities. Among these activities include contamination control. A team consisting of approximately 15 RAT responders are trained in the setup and operation of a Contamination Control Station (CCS).

Contamination Control Station (CCS)

The Contamination Control Station (CCS) is the transition area between the contaminated zone and the clean zone of a radiological incident scene. The CCS is designed to control ingress and egress around the contaminated area, and to employ anti-contamination procedures to eliminate or reduce to an acceptable level (a) contamination of personnel and equipment operating in the controlled area, and (b) the spread of contamination to surrounding areas.[3] Operational procedures for the CCS must remain flexible to allow for variations in both terrain and the myriad of potential accident scenarios. A typical layout is shown in Figure 1.[4]

DESIGN CONSIDERATIONS

Purpose

The CCS Response Vehicle was designed to satisfy the need for a rapid deployment of equipment for the setup of a Contamination Control Station. This deployment may be either on the Pantex Plant site, or, if directed by the DOE Albuquerque Operations Office, to any location in the U.S. or worldwide to a site having radioactive contamination and needing response assets of this type. The external layout and interior plan of the CCS Response Vehicle is shown in Figure 2.

Application Overview

The CCS Response Vehicle remains in a stand-by mode, fully loaded and ready to respond at all times. When deployed to an accident involving radioactive contamination, the vehicle will proceed to a predetermined "safe" distance, upwind of the contamination source(s). This distance may vary, depending on the scenario and hazards involved. Equipment handlers, or "loadmasters", issue items directly from the Vehicle to CCS team members, who set up the contamination control station according to RAT CCS procedures. The CCS Response Vehicle must be able to transport equipment and materials to potentially anywhere on the globe. Thus, the vehicle must necessarily be designed as air transportable. Pursuant to DOE agreements with the Department of Defense, C-5A or C-141 aircraft would be provided for transport when requested for an exercise or actual deployment. The design specifications call for overall dimensions and gross weight commensurate with cargo capacity of the smaller C-141.

Equipment Requirements

In accordance with the typical setup shown in Figure 1, the following equipment is required and must be carried by the CCS Response Vehicle:

- 6 Ludlum Model 12 radiation monitors
- 6 Ludlum Model 2000 swipe counters
- 2 high volume air samplers
- 2 portable gas generators
- 2 10ft. x 20ft. portable awnings w/poles for CCS protection from sun and weather
- 4 rolls herculite ground covering; 54"W x 100 yds. each
- 50 complete sets of "Level C" anti-contamination suits
- 50 pocket ionization chambers and/or thermoluminescent dosimeters
- 6-12 folding 8 ft. tables
- 10 folding chairs
- 6 portable collapsible repositories for the doffing of personal protective equipment

Functional Description

Size & Loadability. In determining overall external dimensions of the vehicle, equipment requirements had to be evaluated against size and gross weight tonnage constraints of the transport aircraft. Typical projection limits and loading configuration are shown in Figure 3. Maximum vehicle overhand was determined empirically, using the load angle of standard ramp shoring for a C-141B. Because the highest point of the vehicle is behind the first wheel going up the ramp, the overall vehicle height can be no more than 102 inches.[5] The optimum overall dimensions were determined to be 280"L x 102"H x 94"W. This called for a vehicle similar in construction and appearance to a commercial ambulance. In order to manufacture a vehicle with this configuration, a specially designed box would have to be fabricated and joined to a standard vehicle chassis.

Chassis/Body. The chassis selected is a Chevy C3500 High Output with 4x2 drive and 6.5 liter turbo-diesel engine. With 180 horsepower at 3400 rpm, and 360 ft-lbs of peak torque at 1700 rpm, this model was determined to offer adequate power and capacity based on possible highway and unimproved road conditions, and a gross vehicle weight of 15,000 lbs.

Figure 1

CCS Layout

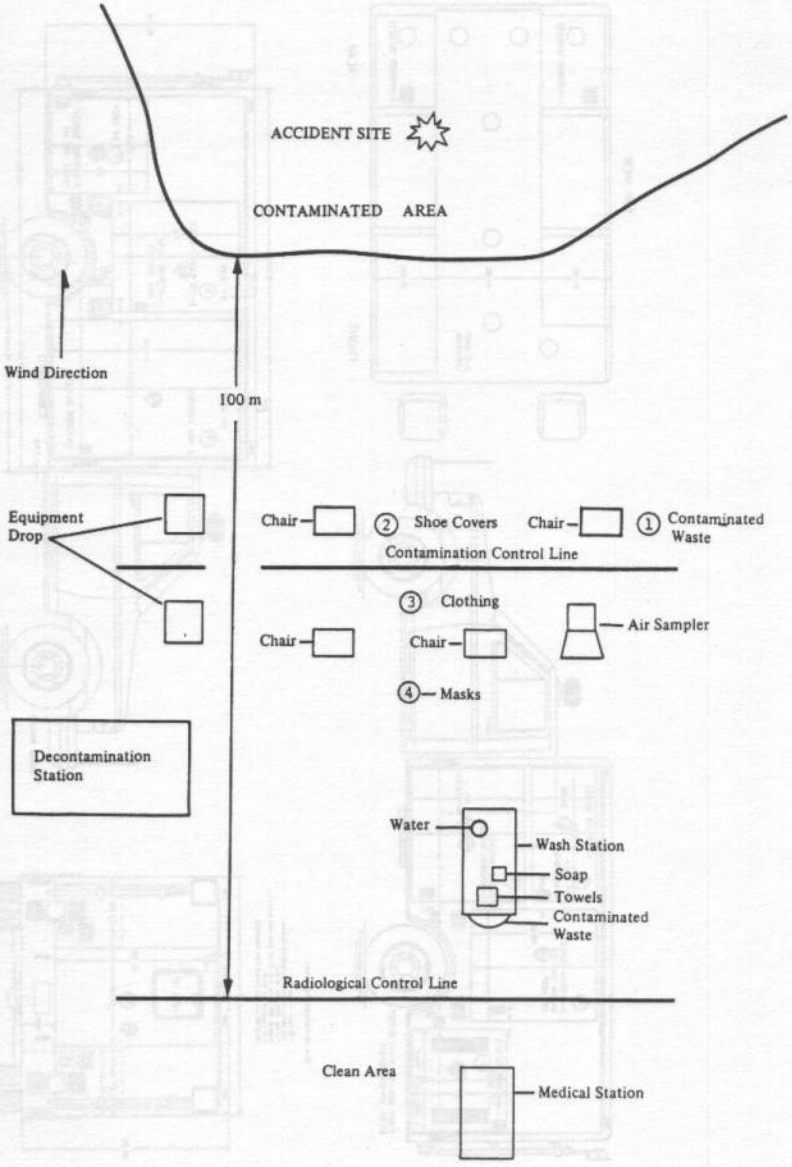

Figure 2
VEHICLE LAYOUT

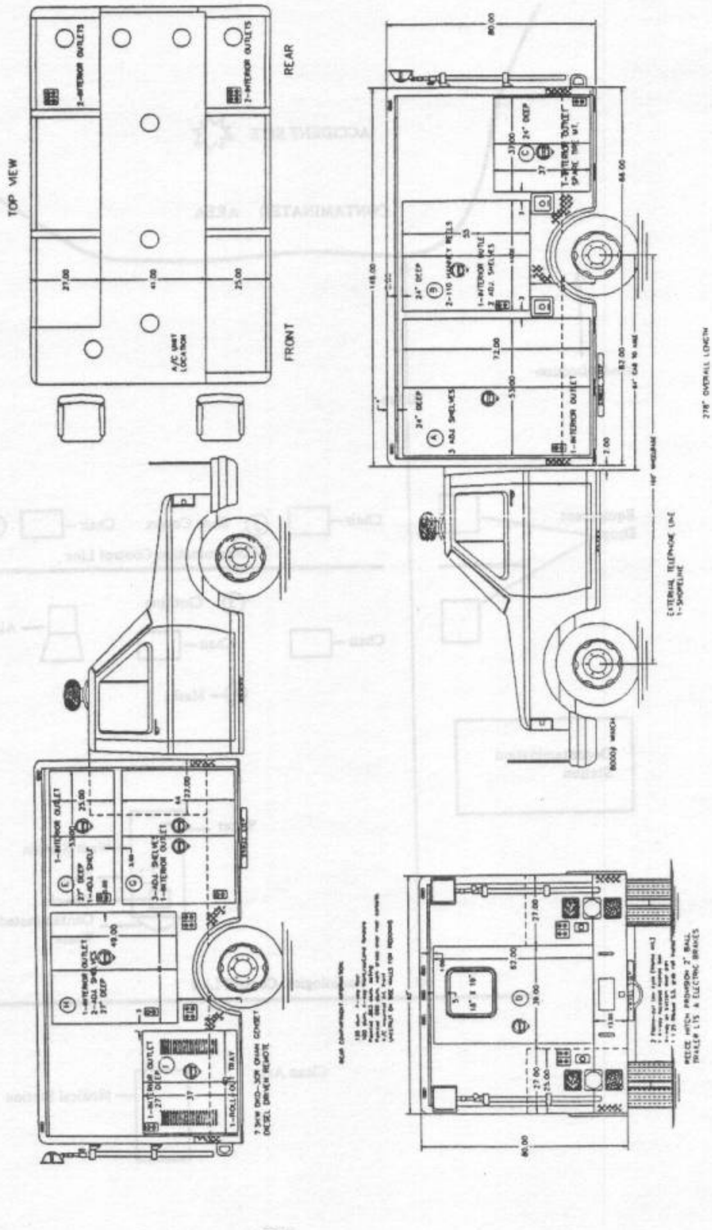

Figure 3

Projection Limits

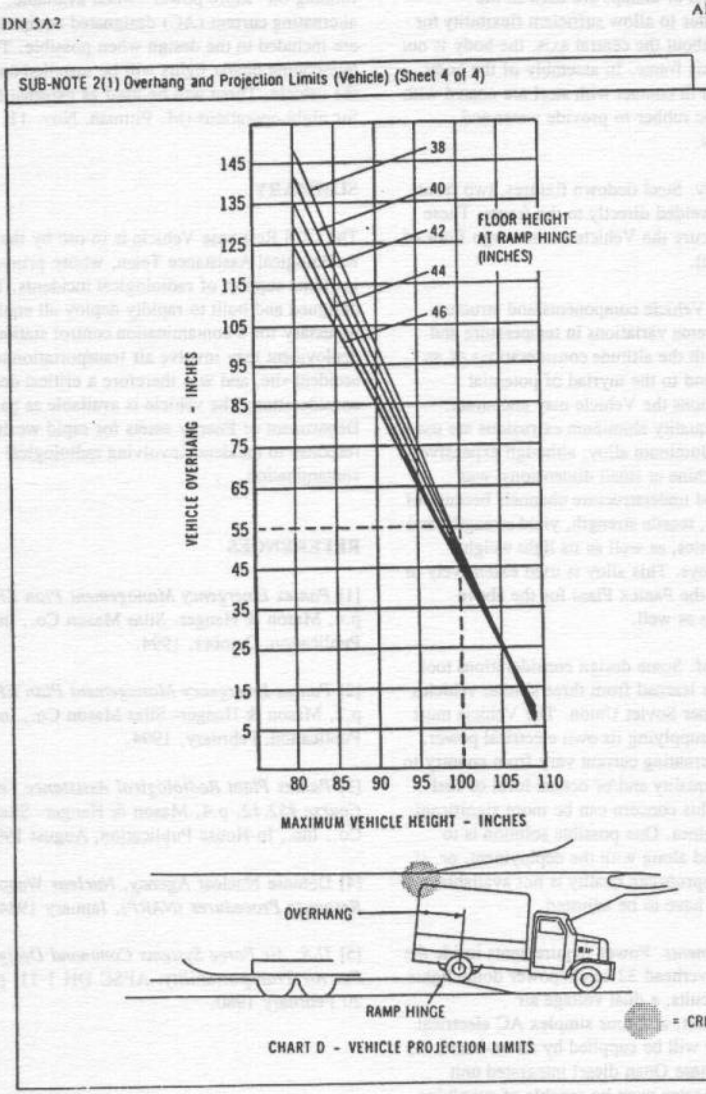

CHART D - VEHICLE PROJECTION LIMITS

Substructure. Structurally, the body is of bolted and welded construction. All parts of the body and attachments are fastened using rust-resistant fasteners in a manner precluding the loosening of any bolts or screws, and the cracking of welded joints. For this reason, no "U"-bolts or clamps are used in the construction. In order to allow sufficient flexibility for bending moments about the central axis, the body is not welded to the chassis frame. In assembly of the body, areas where steel is in contact with steel are coated with a modified synthetic rubber to provide water and corrosion resistance.

Transportability. Steel tiedown fixtures, two front and two rear, are welded directly to the frame. These are necessary to secure the Vehicle to the cargo floor of the transport aircraft.

Metallurgical. Vehicle components and structure must allow for extreme variations in temperature and pressure, due to both the altitude considerations of an airlift deployment and to the myriad of potential climates and conditions the Vehicle may encounter. Prime commercial quality aluminum extrusions are used throughout. 6061 aluminum alloy, although expensive and difficult to machine at small dimensions, was chosen for body and understructure channels because of its superior rigidity, tensile strength, yield strength, and ductility characteristics, as well as its light weight relative to other alloys. This alloy is used extensively in weapons tooling at the Pantex Plant for the above mentioned attributes as well.

Lessons Learned. Some design considerations took into account lessons learned from three similar vehicles supplied to the former Soviet Union. The Vehicle must have provision for supplying its own electrical power, as standards for alternating current vary from country to country. Also, the quality and/or octane level of fuel can vary as well. This concern can be more significant for turbo diesel engines. One possible solution is to have fuel transported along with the deployment, or, if diesel fuel of the appropriate quality is not available, vehicle timing may have to be adjusted.

Power Requirements. Power requirements inside the box include eight overhead 32 candlepower dome lights on two separate circuits, a dual voltage air conditioner/heater unit, and four simplex AC electrical outlet plugs. Power will be supplied by an on-board 7.5 KW, 60 Hz, one-phase Onan diesel integrated unit generator. The generator must be capable of supplying all required electrical power with the vehicle engine turned off. The unit is mounted on roll-out glides for access to maintenance points and to reduce noise inside the vehicle. Additionally, an external 110/120v receptacle is placed at the rear of the vehicle to enable running on "shore power" when available. Therefore, alternating current (AC) designated equipment and lights are included in the design when possible. Two telescoping quartz lights will be installed on the rear of the vehicle. These will be used as external floodlights for night operations (M. Pittman, Nov. 11, 1994).

SUMMARY

The CCS Response Vehicle is in use by the Pantex Radiological Assistance Team, whose primary mission is offsite support of radiological incidents. The unit was designed and built to rapidly deploy all equipment necessary for a contamination control station. This deployment may involve air transportation to the accident site, and was therefore a critical design consideration. The vehicle is available as part of Department of Energy assets for rapid worldwide response to incidents involving radiological contamination.

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PRELIMINARY RESULTS OF THE FIFTH EXPEDITION TO THE SITE OF THE LOSS OF THE SSN "KOMSOMOLETS"

(16.06.94-11.08.94)

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The SSN "Komsomolets" sank in the Norwegian Sea to a depth of 1700 meters as a result of damage which took place in April of 1989. The submarine has one nuclear reactor in a smother state and two nuclear torpedoes on board. After a number of expeditions to the place of loss (1989,1991,1992, and 1993), it was established that the leakage of radioactive products from the nuclear reactor does not influence the environment significantly. The leakage of toxic plutonium-239 was not stopped. The blow of the SSN against the bottom and the explosion in the first part led to the formation of a hole (20 square meters) and, as a result, the hermetization of the front covers of upper torpedo apparatus was broken, as well as their rear parts and torpedo engines. All of this, including flows, became the reason for the flow of water through the bow part of the SSN which, because of intensive corrosion, could lead to the leakage of plutonium from the warheads into the ocean.

In the period from 02.07.94 to 28.07.94, the 5th expedition of the scientific research vessel of the Russian Academy of Science "Academic Mstislav Keldish"--specially organized by the Ministry of Emergencies of Russia--performed work in the Norwegian Sea with two deep-water vessels "Mir" on board. The oceanographic research vessel "Semen Degnev" also participated in the expedition. The expedition was partly financed by the Holland Government through the "Komsomolets" Foundation.

The main goals of the expedition were to carry out tasks preventing the leakage of plutonium from the SSN into environment and to perform oceanographic and radiation monitoring at the accident site.

The following results were achieved in the expedition:

a) Hermetization of the bow of the submarine;

b) Inspection of the SSN and collection of the information necessary for determining proposals concerning the next actions to be taken regarding the submarine--the actions determined will be carried out during the second stage of operations scheduled for 1995-1996;

c) Realization of large-scale oceanographic, bioecological and radiation research in place;

d) Determining concepts for organizing the ecological monitoring in the sites of possible removal of nuclear products from the SSN and burial of the nuclear waste products; and

e) Examining the life-camera to estimate the chancing of raising it during the second stage of works with the SSN.

The main tasks of the expedition were accomplished with the help of deep-water vessels "Mir-1" and "Mir-2". Eighteen (pair) dives took place, the most of them in bad weather conditions.

The crews of the deep-water vessels attached nine covers onto the holes in the bow part of the SSN, six of which were attached to holes of the shields of the torpedo apparatus. Attachment of the covers was accomplished on custom made brackets. So, the project of the first stage of work on preventing leakage of plutonium from the SSN was accomplished. It was the first time that unique underwater work, which plays a big role in the protection of the sea environment, was carried out on a hazardous radioactive object, located at a depth of 1700 meters. The closing of these holes substantially blocked the flow of water through the bow part of the SSN and reduced the possibility and intensity of potential leakage of corrosion products from the submarine.

During the dives of the deep water vessels, damage of the light and hard hull, and the inner constructions of the first compartment of the SSN were examined in detail. Pictures and video films were made. The materials resulting from the examination of the SSN are sufficient for determining further projects according to the second stage of the project to prevent the leakage of plutonium from the SSN "Komsomolets".

The submarine hull was also examined. The resulting materials made it possible to estimate the technical state of the hull and if necessary, to plan the project of raising the camera. General oceanographic research was also made during the expedition. Such research is very important for forecasting the situation in the place of the accident of the SSN in the very near future. A number of hydro-physical studies of the structure of water also took place. The studies included sounding of regulating of temperature, salinity and transparency of water from the surface to the bottom, as well as measuring of speed and changeability of flows in the ground layer with the help of local bottom stations which were used during the 20 days.

Preliminary treatment of the recovered materials showed that during the observation, the main transfer in the ground layer is moving in the northwest direction at a speed of 5-10 cm/sec. It was also discovered that the speed of flow in the ground layer is extremely variable. An underwater storm was experienced during the first expedition that led to zero visibility, because the water was stirred up to 50 meters. The flow and its speed in the region where the operations were carried out changed rapidly depending upon the season of the year. The expedition placed measuring instruments to repair these processes for the long term. Inside the first compartment of the SSN, the speed of the flow sometimes reaches 8 cm/second after attaching the covers. This is proof of the water exchange between the bow part of the SSN and the environment into the water through the break in the first compartment.

The aim of the biological research was to find out any possible ways of migration of radioactive pollution to the food-chains. Different devices like 150 liter barometers, planktonnets, etc., as well as observation through portholes allowed the thorough examination of the chemical composition and distribution of living organisms in the water from the surface to bottom. It appeared there is a possibility to transfer radioactive products through the food-chains from the ground into the surface layers. Scientific institutions also consider the transfer of the lowest layers of the water to the surface. This is possible, but in the summer such displacements were fixed. Four kinds of animals were discovered not far from the SSN. They inhabit all layers of the water, including the surface, where they are eaten by herring and young cod. As the major source of food organisms for herring and other fish are kinds which do not go down to the ground layers, potential carriers of radioactive products can make up no more than 2-3% in their food. Due to the fact that not all the plankton animals rise from the lowest layers and that possible radioactive pollution will be of a local character, direct transfer of radionuclides through trophic chains will not be considerable.

Geological research formed a complex of selection of sedimentary samples in the location of the SSN. Special bioscoops, subsoil tubes and other devices were used for this work. The work was carried out from on-board the ship and deep-water vessels. An important part of this geological program was visual observation through the port-holes of the deep-water vessels.

The research works showed that in the place of loss of the SSN there is a contour flow with a clear, turbid bottom layer. Concentration of the dregs there is 0, 5-0 ,8 mg/l, which is 2-3 times more than in the more transparent upper layer of water. Thin, suspended fractions flowing around the submarine generally don't fall onto the surface of the bottom.

Sedimentary material migrates to the bottom only after the concentration of the tranction into larger food lumps by plankton animal-filtrators and then--as a result of bioturbation--it penetrates into the thickness of sediments. Vertical flows of the sedimentary material of the bottom are 100-300 mg/m a day. Complex oceanographic research provided for main conceptions of longtime monitoring of the ecological system of the Norwegian Sea in the zone of the SSN and the nearest areas of water to be determined .

Radiation monitoring of the SSN and the nearest zone were carried out by means of two deep-water vessels, instruments and devices which were placed on them, including new specially created deep-water gamma spectrometers, barometers, different kinds of sample takers, filter plants, and telescopic instruments, etc. This equipment can be used for monitoring of other dangerous radioactive objects.

Radiation research near the SSN took place on both vessels taking part in the expedition. Primary treatment and measuring of water samples, bottom, and biological objects was done with the help of modern radiochemical methods of isolation of radioactive elements, and different laboratory alpha-, beta-, and gamma-spectrometers. Some of them were worked out specially for this expedition. Some experimental samples by the mass-spectrometer were used for the first time in the sea, and it was a success.

This was also the first time when a longtime module bottom station of radiation control was placed in the region of the SSN location.
The results of radiation monitoring are the following:

a) The measured concentrations and isotope structure of plutonium in the water samples, dregs and bottom sediments are similar to the concentration and structure of plutonium of global fallout. This proves the fact that the corrosion products of any plutonium located in the SSN practically do not go out into the sea.

b) The measured concentration of the main radionuclide of reactor origin (Cesium-137) which is flowing out from the SSN is not more than 2*103 Bk/m3. Therefore, there are no great changes in the radiation state. Nevertheless, the concentration of Cesium-137, measured in the ventilation tube of the reactor compartment, is approximately 200 times more than it was several years before. Now, it is 106 Bk/m3, which makes it necessary to study more thoroughly all the recovered materials to determine the state of the reactor plant more precisely.

Foreign scientists, specialists from MAGATE, the Norwegian Society of Radiation, and all of the defense and ''Komsomolets' Foundation that were invited by the Russian Ministry of Emergencies to take part in the expedition received the necessary information. One of the representatives of the "Komsomolets" Foundation dove from on-board one of the deep-water vessels. As such, he had an opportunity to examine the damage in the lower part of the SSN.

The analysis of the results of the fifth expedition to the SSN "Komsomolets" lead to a number of conclusions:

a) Underwater technical operations carried out on hermitization of the bow part of the SSN are very important for the environment, for its protection from radioactive and toxic pollution;

b) There is no doubt about nuclear and radiation safety of the SSN now. But, it still remains a potential cause for radioactive pollution of the environment. This means that it is advisable to continue the monitoring of the region; and

c) Exchange of water between the first compartment of the SSN and the environment indicates that it is necessary to perform complete hermetization of the submarine. As it is impossible to exclude radioactive and toxic pollution of the environment with all the consequences, plutonium leakage must be prevented. This can be done by closing a big hole in the first compartment which will concentrate plutonium inside the submarine. This is to be done during the second stage of work on prevention of plutonium leakage from the SSN "Komsomolets".

INTERNATIONAL COOPERATION FOR DISASTER MANAGEMENT --ROMANIAN-AMERICAN EXPERIENCE IN THE ACHIEVEMENT OF A JOINT EXERCISE USING DECISION SUPPORT TOOLS FOR RADIOLOGICAL EMERGENCY

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KEYWORD: computer, demonstration, emergency planning, international cooperation

ABSTRACT

International coordination and cooperation is rewarding but at the same time very challenging. This paper will discuss the Romanian perspective on technology transfer, its problems and its advantages. Further, the discussion will take place in the context of preparing for an international conference while at the same time exchanging civil defense expertise. The American perspective on the same subject will also be presented with healthy doses of mutual explanations. The final portion of the paper will present the joint lessons learned from the newly created interfaces and what it holds for the future.

I. INTRODUCTION

In the North Atlantic Cooperative Council (NACC) Seminar, which took place in Romania in September 1994, a computer assisted demonstration was presented, the significance of this demonstration was that it illustrated the successful cooperation between Romania, Bulgaria, and the USA. As important was also the human bond that has been established between those organizations and countries. Involvement in these activities allowed the way towards success despite distances and differences in languages, culture, and tradition. No one claims that the key to success for international cooperation was found, but of course there were a lot of things to learn about. This paper begins with a chapter titled Background, which presents the organizations involved in the activities resulting in the demonstration of cooperation. The paper then closes with a final chapter specially dedicated to the conclusions and lessons learned, but also includes recommendations for the future. The paper aims to present the Romanian and American experts' opinion about the demonstration of using computer technology for helping the international cooperation in the field of disaster management. These experts were directly involved in this effort. What hopes did they have, what have they achieved, and what were their disappointments? There is a little bit of each in this experience that they have gained.

II. BACKGROUND

It is known the importance of bilateral and multilateral contacts regarding emergency planning between nations of Europe, North America and even the world. These contacts may be transformed into an effective cooperation in the field of response to disasters, and in order to be materialized and developed towards the expected direction, sometimes they require support from organizations such as: North Atlantic Treaty Organization (NATO), NACC, United Nations Organization and even the European Union.

Also in order to meet the necessity of a close and effective cooperation between NATO, and Central and East European nations, in November 1992 the USA initiated in these countries the US European Command's Military to Military Contact Program ("MIL-TO-MIL"), which now has Military Liaison Teams in almost all these nations. It is worth to be mentioned that between the Military Liaison Team for Romania and the Romanian Civil Defense Command, a fruitful relationship has been established.

Lately direct relationships were encouraged between the National Guard of the USA and military governments from Central and Eastern European countries. These were materialized in tours for mutual information about the capabilities and requirements for response to all forms of disasters.

In October 13, 1993, in Brussels, the plenary session of the Senior Civil Emergency Planning Committee (SCEPC) of NATO took place. During this session Romania had offered itself to be the host of the Seminar on International Cooperation for Disaster Management to he held during the second half of 1994.

In February 1994, an American team formed by representatives of the Department of Defense (DoD), Federal Emergency Management Agency , NATO, Alabama Army National Guard (AANG) and experts of USASSDC visited Romania. The purpose of the visit was to observe the conditions offered by Romanian Ministry of National Defense, through its Civil Defense Command, for the organization of the Seminar in this country. The visit was also an opportunity for a better understanding of the Romanian civil defense organization system, and its emergency planning, and the establishment of close cooperation relationships between Romanian Civil Defense Command and AANG.

On this occasion it was presented the idea of a demonstration of a computer assisted exercise taking place in this Seminar. This exercise should illustrate the intervention and cooperation activities in case of radiological emergency having a transboundary effect, for a situation involving two neighboring European nations. Romania and Bulgaria were chosen as players in this tabletop exercise, in order to demonstrate this kind of cooperation. The choice was not made accidentally, but taking into account the neighborliness and collaborative relationships in the field of civil defense between these two countries. Technical support, computer experts, and training were to be provided by USASSDC.

What is the importance of this exercise?

Technologically it is a novelty for Central European countries' use in the field of disaster management. Although, Romania and Ukraine were the only former Warsaw Treaty nations that took part in the "First NEA International Offsite Emergency Exercise" organized by the Nuclear Energy Agency of the Organization for Economic Cooperation and Development.

Having on hand the technology and experts everything becomes simple and easy to use. What if some more is tried, for example international cooperation? In the beginning bilateral cooperation between two neighboring countries may be demonstrated, one of them having the risk source on its territory and the other suffering the consequence in case of disaster.

What kind of risk will be demonstrated?

One of the most feared risks nowadays is represented by radiological accidents, especially because of their catastrophic long term consequences and wide areas affected. In Central and Eastern Europe there are nuclear reactors without containment that have a long functioning period. It may be demonstrated that well conceived and applied security measures and well conceived plans may reduce the risk, or in case of an event mitigate the consequences endured by the population. If we also add a good coordination of these plans upon the basis of mutual trust and understanding, this may become an example for a demonstration of computer technology utilization, e.g., Geographical Information System (GIS) at the international level. This could result in international cooperation for response to a radiological emergency situation. In such cases important problems occur because of the existence of many organizations and agencies, each having their own methods, proceedings, communication equipment, and maps to be used for intervention in case of disaster. At this international level the problem may be solved by interoperability, but there are other complex aspects that have to be solved here, such as compatibility and standardization.

During, the SCEPC - NATO plenary session of April 13, 1994, in Brussels, Romania was announced as host country for NACC Seminar on International Cooperation for Disaster Management. The title of the seminar was: "Civil Protection for Changing Times. Realigning War -- Related Civil Defense Programs for All Hazards Emergency Management and Planning for Radiological Accidents".

In his speech of April 13, 1994, the Deputy to the Under Secretary of Defense (Policy) for Policy Support of US DoD mentioned that Romania's national programs for cooperation between civilian government and military civil defense planning is a successful model. He was also impressed by Romania's commitment to realign its military civil defense structure to "all hazards emergency management" during peacetime. He also related that in the seminar hosted by Romania a tabletop exercise on international cooperation in case of radiological emergency would take place.

As a result of the American team visit in Romania in February 1994, beginning with July 16, 1994, a Romanian and a Bulgarian team of experts was prepared with the view to developing the computer assisted demonstration. As for the Romanian partner, this activity was well received and supported by the leadership of the Ministry of National Defense who understood completely the significance and importance of this effort. The financial support of this activity was provided by MIL - TO - MIL Program, and technical support by USASSDC at its headquarters in Huntsville, Alabama. This represented also a new occasion for the

Romanian partner to strengthen the relationship with the Alabama National Guard.

The American experts' team arrived at the place of the conference a week before the beginning of the Seminar, with the view to installing the equipment, finishing the last details and making necessary rehearsals. The first day of the Seminar, dedicated to Romania, allowed a short information about the Romanian civil defense organization system and the main risk sources on Romania territory. There were presented intervention plans for each type of risk, including the CANDU reactor security system -- the first reactor of Cernavoda Nuclear Power Plant (NPP) which will enter into function in 1995.

The second day was dedicated to international presentations, leading the attention to other practical aspects and technologies of the civil defense area. The tabletop exercise was programmed for the third day of the Seminar. The last day of the Seminar, an evacuation field exercise in case of nuclear accident at Cernavoda NPP was organized and carried out by the experts of the Romanian Civil Defense Command. They cooperated with the central and local authorities and representatives of the NPP, which were responsible for these measures.

The Commander of the Romanian Civil Defense Command, co-president of NACC Seminar, had mentioned in his opening remarks that the participation of 22 nation representatives in this conference may be considered as a success. Its' importance is even greater, taking into account the presence of the Principal Director for Emergency Preparedness Policy and the Director for Emergency Planning from the Pentagon, and the Deputy Commander of USASSDC who was present on the third day of the Seminar".

III. ACTIVITIES PLANNING

As mentioned in the previous chapter, the Romanians and the Americans jointly reached the necessity of developing a strong relationship that would permit an unprecedented demonstration of multinational cooperation. Using advanced technology, this demonstration, would illustrate to the participants in the NACC Seminar, held in Romania the realities and possibilities of mutual cooperation to address common disasters.

The initial stages of planning were difficult. There were taken into consideration problems that could appear and affect the common effort. There could be management difficulties, political issues, languages problems, cultural differences, or technology circumstances that would surface and interfere with the planning, development, and conduct of the computer demonstration activities. The approach to working was to envision a suite of contingencies in an effort to address each of the areas of potential difficulty.

Management difficulties generally might appear in getting several layers of organization of each partner to agree on the scenario of the demonstration. If there was substantive disagreement on the text of the demonstration, time to resolve the disagreement would be limited. As it turned out more time than was expected was needed to start first corrections. The significant issue was that there was not much time dedicated to study the computer projected material. This caused some last minute problems. In the remaining hours before the demonstration just how much of the material could be revised and then practiced enough to be polished?

Political issues could potentially have delayed or canceled the effort. Fortunately, these influences created no significant side effects for the common effort. Each party provided details to their government on the objectives and the political way in which the radiological release exercise material would be presented. This matter-of-fact approach, the continuing trust that was developing among partners, and the timeliness of the material on the world stage had positive effects on any political issues.

Language skills were essential, because the American party was not prepared in this matter, the full burden of translation fell on the Romanian partner. The mutual sharing effect of learning to operate the software to be used at the demonstration drew each partner together into a common bond. Amazingly, some two-person conversations used intuition as a successful form of communication.

Other issues taken into consideration at this moment of planning were the cultural and technical ones, although it was hard to envision the effects that might impend over cooperation. It was even considered that the technical aspects would present the least difficulties.

Considering all these factors which until the last moment showed their positive and negative effects, there were still questions. Could the joint exchange of necessary information be achieved and then the meaningful demonstration be developed and conducted for a large multinational civil defense conference? The time line was less than seven months. Could the many coordinations be included within this period of time?

The concerns were many, but first the American party must accomplish what they had promised to the Romanian partner. There was little room for error. The mission would have to be completed in the time allocated.

With this end in view, each partner accomplished major operations that would answer to all contingencies:

- Providing people to become familiar with the software,
- providing necessary conditions for planned activities development,
- taking into consideration multi-sources of data,
- permitting careful agreements on the script by all parties and proper documentation,
- and the inclusion within their programs of non-working experiences in order to get the partners closer.

Moreover, the American partner had assumed the following responsibilities:

- Making available two computers, necessary software, power conditioning equipment, projector and necessary backup supports for computer files,
- carrying out the rehearsals with technical people,
- and performing careful checkouts of software and data sets.

IV. DEVELOPMENT OF PLANNED ACTIVITIES

The cooperation between Romanian and American partners included the discussion of the scenario proposed by the American partner with Romanian and Bulgarian planners, but also, the initiation in and training with GIS of the Romanian and Bulgarian computer experts.

Besides the interest shown for maps, existent programs and plans for emergency automation of intervention management , the American partner had evaluated the Romanian civil defense possibilities to assimilate them into the GIS.

Beginning with February, a long training period was developed by the Romanian partner, using the handbooks and publications received from the USA. The training continued with a practice, during ten days in Huntsville, Alabama, at the headquarters of USASSDC and concluded with a final practice the week prior to the NACC Seminar, in September 1994.

The activity developed in Huntsville was the catalyst of the entire Romanian experts' process. Redundant computers were made available by the American team. The cooperation in this area was accomplished only with experts directly involved in this exercise. When the Romanian team arrived in Huntsville, digital maps were already made by American experts. The Romanian partner mission was to select proper maps for the scenario, and input specific civil defense information into the database and learn to operate the application software "ArcView".

It was a great effort for both partners. Before the departure of the Romanian team from Huntsville, a rehearsal was made in conditions similar to those provided by Romania for the demonstration in the NACC Seminar. Another accomplishment was the detailed discussion of the scenario. It was agreed upon to present the activities carried out within the first 72 hours from the moment of radiological emergency occurrence. The accident was planned for a level 6 or "serious event' on the International Nuclear Event Scale (INES). This magnitude of the simulated accident was chosen in order to imply the intervention and cooperation of neighboring countries and also of international organizations.

Romania was represented on the panel by the Commander and members of Romanian Civil Defense Command, Regional Chiefs of Staff of Civil Defense, Representatives of Ministry of Agriculture and Food, Ministry of Health, Ministry of Waters, Forest and Environmental Protection and the Romanian Regulatory Body -- National Commission of Nuclear Activities Control. Bulgaria was represented on the panel by the National Director of Civil Defense, the Regional Director of Civil Defense, and the Plant Manager (Safety Director).

Taking part together at these activities friendships were begun and nurtured between members of the teams. Programs of shared non-working experiences were implemented by both partners that heightened the feeling of camaraderie. At the onset the Americans were somewhat cautious. However the Romanians were immediately open and warm. This quickly cleared the atmosphere for mutual trust in the joint capability to accomplish this time sensitive program.

V. THE DEMONSTRATION

"Disasters have no boundaries" is obvious and valid for everybody, politicians and experts. Disasters strike countries no matter what economic level they have, people's pains and tributes to the consequences being the same.

Referring to radiological emergency, an illustrative example is the accident at Chernobyl NPP, with serious consequences not only for the former USSR, but also for neighboring countries. After this event, the majority of countries have reevaluated their radiological emergency plans and improved the training of the personnel responsible for their implementation. With this end in view, a standardization process at international level has been developed for specific procedures in this kind of emergencies. So, the response activities would be closer and in agreement with each country's legislation. This process is still developing.

An important role for an effective activity in case of radiological emergency is held by experts' trained within the structures and bodies responsible for decision making, and analysis. An important role is also held by technical support provided for this process. In case of a nuclear transboundary accident it has to be added an early notification and information sharing, on the basis of protocols, agreements and conventions is essential. This aspect involves observing the Convention on Early Notification and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency. These conventions stipulate the mutual assistance given by different countries, or by international organizations in order to cope with these events. These were some of the issues emphasized within the demonstration scenario of the computer assisted exercise presented during NACC Seminar.

The scenario proposed by USASSDC had the title "Decisions Support Tools for Disaster Management." It illustrated how two neighboring countries cooperate in case of nuclear accident with transboundary effect, both at local and national levels, and at international level. This kind of tabletop exercise aims to demonstrate the support that the computer and an appropriate software may provide for experts' training in different emergency situations.

At the end of almost seven months of preparedness, on the third day of the Seminar everything was ready for the exercise, both the equipment and technical people involved in this effort. The Demonstration included several modules, each of them relating to a specific response phase of a nuclear accident: Scenario Introduction, Notification Phase, Response Phase, Hazards, Remediation Phase, Questions and Answers and Lessons Learned, covering 4 hours. One of the panels had represented the country that holds the nuclear power plant as the source of the hypothetical accident and the other had represented the affected country. A moderator had the role of asking questions, related to the topics of the modules, to panelists and representatives of international organizations.

The panelists answered the questions referring to the emergency plans of the nuclear power plant and civil defense organizations at local and national level; evaluation of emergency support between affected countries and from international organizations; support operations such as search and rescue, law enforcement, public affairs, radiation monitoring, communication systems, and public protection -- sheltering, decontamination, medical support, transportation and evacuation; evaluation of the existent agreements between affected countries, international conventions, the role of International Atomic Energy Agency and actions undertaken by this organization in such situations. At the same time there were discussed: notification and warning system for the population; activity of different establishments in case of radiological release; emergency protection actions which would be taken within the first hours to protect the population; activation of response forces and how the medical support is provided to affected people; plans for decontamination of personnel and vehicles; short-term measures undertaken for agriculture products, before the arrival and after the passing of the plume of radioactivity; and precautions and levels of radiation that are considered dangerous.

The panels also discussed some long-term remediation measures related to recovering, decontamination, precautions and medical support and long-term programs for monitoring the health of the population, and monitoring and response to long-term effects of contamination to agriculture.

The presence of the computer was an efficient support in presenting and motivating the aspects included within the modules of the scenario. Digital maps helped the early evaluation of the situation and the database helped optimization of the measures taken for public protection.

Thus, it was demonstrated the support offered by GIS in situational assessments and decision making in case of emergency. The scenario tried to illustrate the multi-aspects that may occur in case of radiological emergency. This represented an opportunity for the panelists and representatives of international organizations to show their operation and decision making in such situations.

VI. CONCLUSIONS AND RECOMMENDATIONS

What criteria does one use to judge success or failure in a multiple lingual, cultural, technical effort?

The open-minded relation between people and their nations transformed technical language, associated with intuition, into a common language.

Humanitarian aspect of the activities presented in this paper brought together people involved in a joint effort. This helped then to know and understand each other better, to turn to good account spiritual and cultural riches of their countries.

Technical issues demonstrated the most potential for failure because of unpredictable elements.

No matter what issue is taken into consideration, it is recommended to keep a reasonable number of contingencies opened.

For Romanians this participation in the tabletop exercise preparedness was a good opportunity to consider thoroughly emergency plans at local and national level, to bring some procedures up-to-date and improve the training. The contact, with the Bulgarians, also involved in this effort represented a step forward toward transparency, a closer and deeper cooperation in the field of civil defense, not only for radiological emergency. This illustrates the importance of information exchange regarding risk zones that includes parts of a neighbor country, both in the purpose of a correct emergency planning and a timely starting of response activities.

A nuclear accident is a very complex event and that is the reason why, because of the short time, all the aspects wished to be presented could not be covered. Many questions asked during this demonstration had a general character, which involves long answers to be comprehensive. This situation caused a shortening of Questions and Answers Module. It would have been better maybe if only some aspects, considered important, were used to emphasize a certain area and detail it for the wished level.

Of course, beside bilateral cooperation, international cooperation has an important role, both for the experience of exchange between countries and for helping with resources in massive intervention operations, that cannot be timely carried out by their own means. Another aspect of Romanian-American cooperation in this effort is the transfer of technology in the field of disaster prevention and limitation of consequences. This transfer takes place from a developed country towards developing or less developed countries. This is also an important direction to follow for reducing differences between countries in addressing any kind of disasters.

Romanian-American cooperation in achieving this tabletop exercise has demonstrated the existence of an assembly of factors that support this kind of efforts. The existence of modern training and intervention technologies, of plans which can include these technologies for the benefit of users, of experts who are able to establish a common language that helps the implementation of the plans when disaster strikes countries simultaneously are all examples.

Another positive aspect was the demonstration that, for this kind of cooperation between two countries -- Romania and Bulgaria is just an example -- the existence of a third partner, as an objective observer with the role of catalyst, has a major importance. Supporting this effort, this partner may become a guarantor of the success.

The key that will pull the partners together in a successful effort is the development of mutual trust and friendship.

All these briefly presented activities represent a proof for the possibility to extend in the humanitarian area the major activities of the Partnership for Peace Program.

TIEMEC '95

CHEMICAL HAZARDS

TIEMEC '95

Chemical Stockpile Emergency Preparedness Program Issues I: United States Perspectives on Chemical Emergencies

Chair:
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THE CHEMICAL STOCKPILE EMERGENCY PREPAREDNESS PROGRAM: MANAGEMENT CHALLENGES

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ABSTRACT

The Chemical Stockpile Disposal Program (CSDP) was initiated in response to the 1986 Congressional mandate (by Public Law 99-145) to rid the United States of the aging stocks of chemical munitions. After a thorough examination of the risks involved in the transporting and disposing of the stocks and driven by the congressional mandate to protect the public, the Army decided to build incinerators at each of the eight installations. The Final Programmatic Environmental Impact Statement for the CSDP found that emergency planning for an accident was inadequate in the communities surrounding storage sites. The Army's Record of Decision subsequently committed the Army to enhanced emergency planning. This paper discusses the evolution of the emergency preparedness program since 1986. The program has gone through two significant changes in management approaches. In 1988 a joint steering committee and 6 subcommittees were created. Recently, a new organization within the Army was created to manage CSEPP. This paper reviews origins of the committee approach in CSEPP as well as its strengths and weaknesses. Furthermore, the paper discusses how the new organization should provide more effective management of the program.

INTRODUCTION

The Chemical Stockpile Disposal Program (CSDP) was initiated in response to the 1986 Congressional mandate (by Public Law 99-145) to rid the United States of the aging stocks of chemical munitions. After a thorough examination of the risks involved in the transporting and disposing of the stocks and driven by the congressional mandate to protect the public, the Army decided to build incinerators at each of the eight installations. The Final Programmatic Environmental Impact Statement (FPEIS) for the CSDP found that emergency planning for an accident was inadequate in the communities surrounding storage sites. The Department of the Army's (DA) Record of Decision (ROD) subsequently committed the Army to enhanced emergency planning. This paper discusses the evolution of the emergency preparedness program since 1986. The program has gone through two significant changes in management approaches. In 1988 a joint steering committee and 6 subcommittees were created. Recently, a new organization within the Army was created to manage CSEPP. This paper reviews origins of the committee approach in CSEPP as well as its strengths and weaknesses. Furthermore, the paper discusses how the new organization should provide more effective management of the program.

Chemical Stockpile Characteristics And Distribution

Although the size of the United States chemical stockpile is generally classified for national security reasons, information on distribution is available. Chemical agents, predominantly GB, VX, H, HD, and HT, are stored at eight installations: Tooele Army Depot, Utah (42.3% of the total stockpile); Pine Bluff Arsenal, Arkansas (12.0%); Umatilla Depot Activity, Oregon (11.6%); Pueblo Depot Activity, Colorado (9.9%); Anniston Army Depot, Alabama (7.1%); Aberdeen Proving Ground, Maryland (5.0%); Newport Army Ammunition Plant, Indiana (3.9%); and Blue Grass Army Depot, Kentucky (1.6%). The remaining 6.6% of the stockpile is located outside of the continental United States at Johnston Island in the Pacific Ocean. All percentage figures are based on weight.

The chemical agents are stored in three basic configurations: (1) projectiles, cartridges, mines, and rockets containing propellant and/or explosive components; (2) aircraft-delivered munitions that do not contain explosive components; and (3) steel one-ton containers. Most of the stockpile (61%) is in the latter form. All of the agents are at least 20 years old; some are more than 40 years old.

Each stockpile is stored in a chemical exclusion area at each installation. Most of the stockpile is kept on pallets, in boxes, in cans, or is stored individually in igloos specifically designed for ammunition and explosives. The igloos have lightning protection systems and steel doors, and they are covered with earth. They are equipped with multiple locking systems.

Some one-ton containers of mustard and VX agents are stored in warehouses or outside; when outside they are secured with chains. In either case, they are stored within an exclusion area.

Extensive security precautions protect exclusion areas. Access is strictly controlled by security forces, intrusion detection devices, barricades, and perimeter lighting.

CSEPP Planning Process

The CSEPP is a joint FEMA/Army program to develop effective emergency response capabilities at each of the eight chemical agent stockpile locations. As depicted in Fig. 1, the CSEPP planning process ultimately translates the programmatic Emergency Response Concept Plan (ERCP) into site-specific emergency response plans for each location.

The emergency planning process progresses along complementary paths. One path defines the scope of necessary planning and specifies the emergency preparedness guidelines to be met. The path leads from the programmatic ERCP to this planning guidance document including the appended guidelines. The guidelines will be applied in producing the site-specific emergency response plans. Overall, this path provides federal direction in attaining maximum protection.

A second path develops the site-specific analyses that shape application of the guidelines at each stockpile location to meet local conditions and requirements. In this path, technical analyses have been used to translate the programmatic ERCP into site-specific emergency response concept plans. Each site-specific ERCP will be replaced by an Emergency Planning Guide (EPG). This path will be augmented by local officials to produce community-based emergency planning proposals which, upon approval and subsequent funding, will be made operational through the site-specific emergency preparedness programs. This path provides maximum protection of the public by applying the concepts of the ERCP to each stockpile location.

There is continual interaction among elements of the planning process (e.g., the scope of planning identified in the planning guidance document influences the technical and demographic data collected for the site-specific EPG, and vice versa). As new information is developed in either of the paths described above, it is integrated into a third path that upgrades the interim emergency response plans at each stockpile location. This integration is an iterative process that will be complete when planning guidelines have been fully specified and all relevant site-specific data have been collected and analyzed. At that point the paths converge in an emergency response plan for each location which prescribes effective responses for all foreseeable chemical agent emergencies.

Program Organization

The administrative framework within which CSEPP is being implemented is extremely complex and includes numerous interacting state, local, FEMA, and Army agencies. This section first discusses the history of the CSDP, including the Congressional mandates and the major steps that have been taken in the program. The section next describes the responsibilities of the DA and FEMA as assigned to each of the two agencies by their Memorandum of Understanding (MOU) regarding the CSEPP. The section concludes with a brief discussion of the composition and basic responsibilities of local area planning groups.

The United States currently has chemical agents and weapons stored at eight Army installations within the continental United States (CONUS). Public Law (PL) 99-145, Title 14, Part B, Sect. 1412, directs the Department of Defense (DOD) to dispose of the lethal unitary chemical agents and munitions. The July, 1986, *Draft Programmatic Environmental Impact Statement* (DPEIS) considered four disposal alternatives for the chemical agent stockpile:

(1) disposal at each storage location (i.e., eight sites),
(2) disposal at two regional centers,
(3) disposal at one national center, and
(4) continued storage at each location.

In January 1988, the Army issued a *Final Programmatic Environmental Impact Statement (FPEIS) for the Chemical Stockpile Disposal Program(CSDP)*. The FPEIS examined critical site-specific issues in sufficient detail to compare the alternatives and to recommend one alternative. In February, 1988, the Army issued a ROD that state-of-the-art, on-post incineration was the preferred alternative at each of the eight storage locations. Final implementation of the program depends on annual funding by Congress.

In July, 1987, the Army released the *Draft Emergency Response Concept Plan (ERCP)* for the CSDP. The ERCP presented a conceptual basis for developing local emergency response programs for the CSDP and the various emergency planning alternatives. The concepts in the guidance document are based on the ERCP and other federal guidelines and criteria.

The Army then prepared and submitted to Congress a Chemical Stockpile Disposal Implementation Plan containing program schedules and budgetary requirements. The Army requested funds, based on estimates, to implement enhanced emergency preparedness both on-post and off-post at all eight installation sites. The funds were intended to help the Army carry out its responsibility for ensuring that viable on-post chemical emergency plans and off-post emergency response plans existed for each storage location. In March, 1988, the Army told Congress that implementation of emergency response concepts for each site would cost an estimated $100 million (U.S. DA, 1988b).

The August 1988 FEMA/Army MOU delineated the Army's and FEMA's respective roles. FEMA operates under the following authorities:

- Executive Order 12148;
- Public Law (PL) 96-342; and
- The Emergency Planning and Community Right-to-Know Act of 1986 (Title III of PL 99-499).

Executive Order 12148 delegates authority to

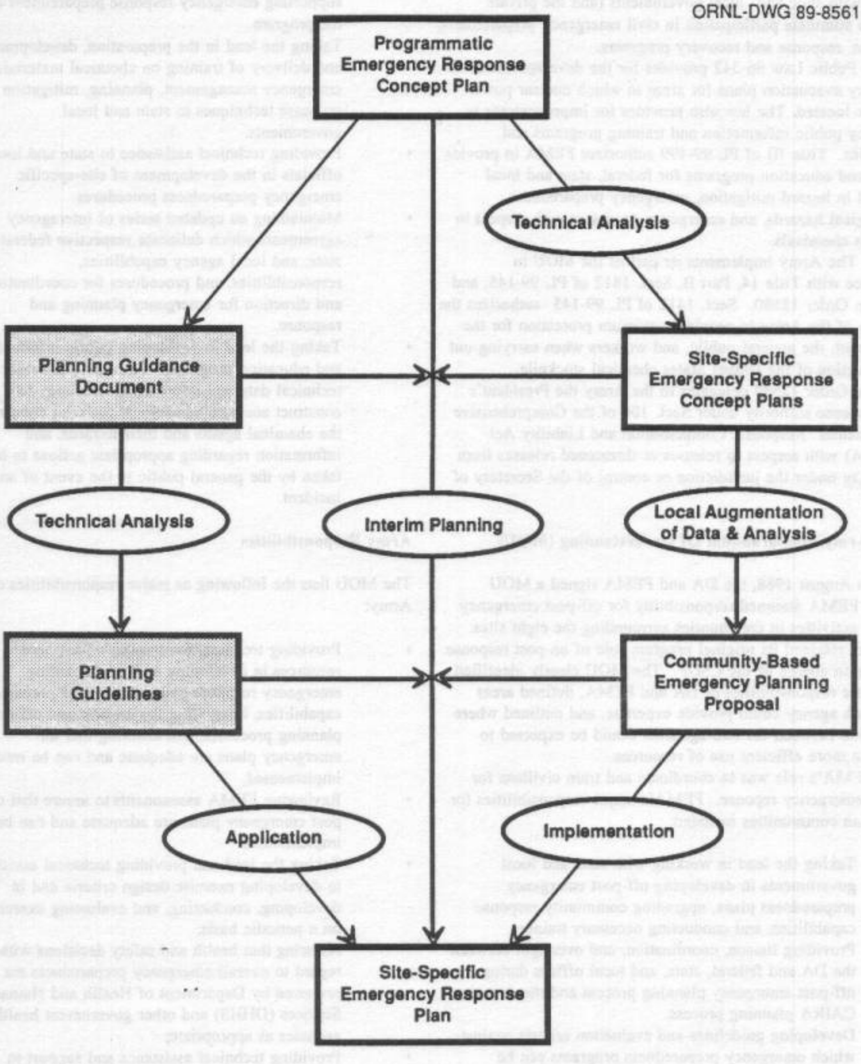

Fig. 1 The Chemical Stockpile Emergency Preparedness Program process.

FEMA to develop policies which provide that all civil defense and civil emergency functions, resources, and systems of Executive agencies are developed, tested, and utilized to prepare for, mitigate, respond to, and recover from emergencies. The Director of FEMA is also authorized to represent the President in working with state and local governments (and the private sector) to stimulate participation in civil emergency preparedness, mitigation, response and recovery programs.

Public Law 96-342 provides for the development of emergency evacuation plans for areas in which nuclear power plants are located. The law also provides for improvements in emergency public information and training programs and capabilities. Title III of PL 99-499 authorizes FEMA to provide training and education programs for federal, state and local personnel in hazard mitigation, emergency preparedness, technological hazards, and emergency processes with respect to hazardous chemicals.

The Army implements its part of the MOU in accordance with Title 14, Part B, Sect. 1412 of PL 99-145, and Executive Order 12580. Sect. 1412 of PL 99-145 authorizes the Secretary of the Army to provide maximum protection for the environment, the general public, and workers when carrying out the destruction of the United States chemical stockpile. Executive Order 12580 delegates to the Army the President's broad response authority under Sect. 104 of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) with respect to releases or threatened releases from any facility under the jurisdiction or control of the Secretary of Defense.

FEMA/Army Memorandum Of Understanding (MOU)

In August 1988, the DA and FEMA signed a MOU whereby FEMA assumed responsibility for off-post emergency planning activities in communties surrounding the eight sites. The Army retained its original program role of on-post response and being in charge of the CSDP. The MOU clearly identified the specific responsibilities of DA and FEMA, defined areas where each agency could provide expertise, and outlined where cooperation between the two agencies would be expected to result in a more efficient use of resources.

FEMA's role was to coordinate and train civilians for off-post emergency reponse. FEMA's major responsibilities for the civilian communities included:

- Taking the lead in working with state and local governments in developing off-post emergency preparedness plans, upgrading community response capabilities, and conducting necessary training.
- Providing liaison, coordination, and oversight between the DA and federal, state, and local offices during the off-post emergency planning process and the Army's CAIRA planning process.
- Developing guidelines and evaluation criteria against which emergency preparedness programs can be assessed for adequacy and assurance that they can be implemented.
- Developing, scheduling, and conducting exercises to evaluate the effectiveness of emergency preparedness programs at each site.
- Serving as a conduit for providing funds available from the Army to state and local governments for supporting emergency response preparedness for the program.
- Taking the lead in the preparation, development, and delivery of training on chemical materials emergency management, planning, mitigation and response techniques to state and local governments.
- Providing technical assistance to state and local officials in the development of site-specific emergency preparedness procedures.
- Maintaining an updated series of interagency agreements which delineate respective federal, state, and local agency capabilities, responsibilities, and procedures for coordination and direction for emergency planning and response.
- Taking the lead in developing public information and education programs. The Army provides the technical data and information necessary to construct accurate educational material concerning the chemical agents and their hazards, and information regarding appropriate actions to be taken by the general public in the event of an incident.

Army Responsibilities

The MOU lists the following as major responsibilities of the Army:

- Providing technical assistance and required resources in developing and implementing emergency response plans and related preparedness capabilities, integrating the on-post and off-post planning processes, and ensuring that all emergency plans are adequate and can be readily implemented;
- Reviewing FEMA assessments to assure that off-post emergency plans are adequate and can be implemented;
- Taking the lead and providing technical assistance in developing exercise design criteria and in developing, conducting, and evaluating exercises on a periodic basis;
- Assuring that health and safety decisions with regard to overall emergency preparedness are reviewed by Department of Health and Human Services (DHHS) and other government health agencies as appropriate;
- Providing technical assistance and support to FEMA in preparing chemical emergency training materials and procedures and participating in

delivering such training to state and local emergency responders, where appropriate; and, finally,

- Taking the lead in conducting site-specific hazard analyses used for the emergency preparedness plans.

ARMY/FEMA Joint Responsibilities

In addition, the MOU identifies some areas of joint effort between FEMA and the DA:

- Determining the funding requirements by fiscal year to develop and implement emergency preparedness programs;
- Cooperating in the development and implementation of program initiatives to integrate the planning and preparedness functions of FEMA and DA related to emergencies involving chemical warfare agents;
- Establishing a FEMA/DA committee to meet on a quarterly basis, or more frequently if necessary, to review the status of joint programs, to discuss and resolve issues, to consult on major policy issues, and to provide the necessary direction to meet DA's overall goals for the program;
- Cooperating in determining exercise requirements for installations and state and local governments as well as jointly develop and evaluate such exercises;
- Developing and implementing a community relations program to include FEMA and DA personnel working with local public officials and interest groups; and
- Encouraging private sector initiatives beneficial to the state and local government agencies responsible for preparedness.

Implementing the MOU

In February 1994, the initial management structure of CSEPP was fundamentally revised. Previously, the Army and FEMA had cooperatively managed the program through a Joint Steering Committee (JSC) that had six subcommittees to oversee the functional areas of the program (Planning, Automation, Public Affairs, Exercises, Training, and 6). Efforts to enhance the preparedness of Army installations and off-post communities were pursued individually by the subcommittees subject to review and approval by the JSC. Each subcommittee was formulated to included representatives of state and/or local jurisdictions participating in CSEPP.

However, it was clear that the subcommittee approach was not working to the best interest of the program. The steering committee lacked the means to manage the day to day operations of the program, lacked a rapid and effective decision making process, and could not coordinate the efforts of the various subcommmittees. Furthermore, subcommittees competed for program resources. This led at times to duplicated efforts, and at other times to important areas being ignored. For example, the automation subcommittee was developing an automation system that did not support the implementation of the planning guidance being developed by the planning subcommittee. On the other hand, protective clothing issues for emergency workers, a topic that cut across many subcommittee interests, was not being delt with. This organizational structure was changed when the Army and FEMA adopted a Joint Memorandum for the Record in February, 1994. This memorandum streamlined the program and enhanced the cooperative relationship between the Army and FEMA in managing the CSEPP. Under the memorandum, the Army continued to have the lead in all affairs of CSEPP. FEMA supports the Army by working with state and local governments in developing off-post emergency preparedness plans, upgrading response capabilities, and conducting necessary training. The Army coordinates on-post preparedness plans, upgrades response capabilities, conducts necessary training, and integrates on-post and off-post emergency preparedness capabilities. FEMA and the Army will jointly develop protocols for assessing the readiness of state and local jurisdictions and Army installations. FEMA regional offices will continue to review civilian emergency plans and evaluate off-post exercises and training.

Under the 1994 Joint Memorandum, the Joint Steering Committee and its six subcommittees were replaced by an Executive Council that is co-chaired by the Principal Deputy Assistant Secretary of the Army for Installation, Logistics and Environment (I,L & E) and the Deputy Associate Directory of FEMA for Preparedness, Training and Exercises. The Executive Council meets quarterly, with additional meetings as needed to resolve issues, ensure timely decisions, and provide policy guidance as appropriate. Representatives of state and local jurisdictions provide input to Executive Council deliberations as appropriate.

The 1994 Joint Memorandum also calls for establishment of a central CSEPP office at the U.S. Army Chemical and Biological Defense Command (CBDCOM). This office will provide a central focus for CSEPP within the Army, implement the program on Army installations, and coordinate and integrate on- and off-post activities. The office is staffed with both FEMA and Army personnel. Staff of the office also serve as members of Site Support Teams.

The Joint Memorandum established a CSEPP Review Panel which conducts quarterly in-progress reviews (IPRs) for each functional area of the program and for each site. At each IPR, the CBDCOM Site Support Teams will present status reports along with input obtained from state and local jurisdictions.

CONCLUSIONS

The Army has initiated a planning effort at each of the chemical stockpile disposal locations that has included state and local agency briefings, Army installation participation, and technical and financial assistance to state and local governments for initial planning activity. CSEPP strives to seek a continuing effort toward achieving a complete and comprehensive emergency preparedness program for both continued storage operations and the eventual demilitarization activity. This process requires continued close coordination between the Army installation personnel and off-post agencies. All local and state agencies that have a role in emergency response are incorporated into the planning effort. This includes State Emergency Response Commissions (SERCs) and Local Emergency Planning Committees (LEPCs) established under the Superfund Amendment and Reauthorization Act of 1986 (SARA), Title III.

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THE CHEMICAL STOCKPILE EMERGENCY PREPAREDNESS PROGRAM: PROGRESS TOWARD MAXIMUM PROTECTION

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ABSTRACT

The goal of CSEPP is to provide maximum protection for communities surrounding the 8 chemical weapons storage and disposal sites. The road map to maximum protection is laid out in the CSEPP Planning Guidance and its technical appendices. The purpose of this paper is to reflect on the progress made on implementing CSEPP as of September 1994. The paper does this by highlighting key and innovative aspects of the CSEPP planning guidance and appendices, discussing the CSEPP benchmarks, and reviewing the status of major emergency systems recommended by the CSEPP planning guidance and appendices. These include indoor and outdoor alert/notification systems, communications systems, and automation systems. Progress in training, exercise and public affairs is also discussed. Data for the paper comes from several surveys conducted in June and September of 1994. The paper concludes that CSEPP is making solid progress towards state-of-the-art emergency preparedness which will also serve to enhance planning for other hazards.

INTRODUCTION

In October of 1993 the Federal Emergency Management Agency (FEMA) reorganized along functional lines. With reorganization and restructuring completed, FEMA's overall redefined mission now reads:

"The mission of the Federal Emergency Management Agency is to:

reduce the loss of life and property and protect our institutions from all hazards by leading and supporting the Nation in a comprehensive, risk-based emergency management program of mitigation, preparedness, response and recovery."

In light of that mission, FEMA is in the process of defining goals and customer-oriented objectives based on an all hazard approach. These goals stress creating partnerships with various agencies and organizations involved with disasters, a national comprehensive emergency management system, an emphasis on hazard mitigation, rapid response and recovery functions, stronger state and local management, and a revitalized FEMA. CSEPP or the Chemical Stockpile Emergency Preparedness Program is being implemented in a manner which is consistent with this new mission.

CSEPP was created to protect the public from an accidental release of nerve and blister agents. In December, 1985, Congress directed the Department of Defense to destroy the obsolete U.S. stockpile of unitary chemical agents and munitions in such a manner as to provide:

"maximum protection of the environment, the general public, and the personnel who are involved in [such] destruction" [Public Law 99-145 (50 USC 1521)]

Under Secretary of the Army, James R. Ambrose, reinforced the concept of "maximum protection" in the Army's 1988 programmatic record of decision (ROD). The ROD called for enhanced emergency preparedness as a means of mitigating the effects of an accident. Emergency planning as a mitigation strategy, subsequently was cited as a major factor in the decision to pursue on-site destruction of munitions as it would be far more difficult to mitigate an accident during off-site transport of the munitions.

This paper discusses the progress in the CSEPP through the fiscal year 1994 in three areas:

1. the planning guidance for emergency planning in CSEPP communities,
2. the CSEPP benchmarks, and
3. the status of major emergency systems recommended in the CSEPP guidance documents that define operational and functional preparedness.

A companion paper (See D. Fisher, "The Chemical Stockpile Preparedness Program: Management Challenges") discusses the organizational structure of the CSEPP.

One of the driving forces for examining the CSEPP accomplishments was the Government Accounting Office's (GAO) audit of the CSEPP in fiscal year 1993. That audit led to congressional hearings by the Environment, Energy and Natural Resources Subcommittee of the House Government Operations Committee, chaired by Mike Synar of Oklahoma in September of 1993. Major issues raised at the hearings included:

- the status of siren installation;
- finalizing the requirements for Tone Alert Radio Systems (TARS);
- finalizing the emergency planning guidance documents;
- evaluating protective clothing for emergency responders and the training to use it; and
- dealing with reentry issues.

Next year the issues are likely to center on the liability aspects of restoration and other legal problems. There is also likely to be some resolution of the issue on evacuating and/or sheltering in place, with or without enhanced or expedient measures.

Emergency Planning Zones

In order to understand CSEPP it is necessary to discuss how it uses a risk based approach to planning. Emergency response plans must reflect the fact that a release of chemical agent will affect different areas in different ways and at different times. Areas near the point of release are likely to experience relatively high concentrations of agent very quickly, while areas farther away are likely to experience lower agent concentrations after a longer period of time. Consequently, the appropriate response actions will differ depending on the time available to implement protective actions. This section describes a method of dealing with these area-based differences in the emergency planning phase. The section describes the concept of EPZs and provides guidance on how the zones should be defined and what types of emergency response actions are appropriate for each zone.

For CSEPP, the EPZ concept involves three concentric zones. This concept reflects the differing response requirements associated with a fast-breaking chemical event with limited time for warning and response. The innermost planning zone is the immediate response zone (IRZ), the middle zone is the protective action zone (PAZ), and the outermost zone is the precautionary zone (PZ).

Planning Guidance and Guidelines

In July, 1994, revised planning guidance was jointly issued by the Army and FEMA (U.S. Department of the Army and Federal Emergency Management Agency, 1994). The July version of the guidelines clarified some cloudy issues, provided revised guidance on alert and notification systems, and included new appendices on protective actions, decontamination, emergency worker operations, and automation systems. Only the appendices on medical services and recovery remain in draft form at this point.

The guidance document serves three principal purposes in the CSEPP:

- It promotes the development of an effective, complete, and comprehensive emergency response capability at each chemical agent stockpile location by providing guidance and direction to assist state, local, and Army installation planners in formulating, coordinating, and maintaining effective emergency response plans;
- It ensures that critical planning decisions are made consistently at all eight chemical agent stockpile locations by establishing a single adequate and systematic framework for emergency response planning related to the CSEPP; and
- It provides a basis for assessing the adequacy of emergency preparedness planning as a part of the evaluation of proposals for federal assistance.

CSEPP Benchmarks

In May, 1993, the Army and FEMA established nine benchmarks to set priorities for the program. The benchmarks, which set the priorities for funding state and local budget requests, include:

- Functioning Alert and Notifications System for installations, IRZs and transition zones.
- Functioning Emergency Operations Centers (EOCs) for each installation and IRZ county.
- Functioning communications system between the IRZ counties and the installations, and between the EOCs, the installations, the Joint Information Centers (JICs) and the States.
- Functioning automated data processing (ADP) systems connecting critical installation facilities with on- and off-post EOCs, JICs, and State EOCs.
- Training programs consistent with the FEMA's State Training Plan (for off-post jurisdictions) and the Army's certification requirements (for on-post installations) and intended to maintain proficiency of emergency services providers, responders, and CSEPP staff, as defined and measured by the CSEPP standards.
- Exercise programs consistent with Joint Steering Committee-approved exercise policy.
- Community involvement programs for public information and education.
- Personnel (such as CSEPP coordinators, public information, public affairs officers, planners, and ADP specialists) to support CSEPP activities on the installations, in the States, and in the IRZ counties.
- Coordinated plans in conformance with established CSEPP Guidance for each installation, State, IRZ county, and PAZ county; plans are to be updated as CSEPP standards are revised or as circumstances within jurisdictions change.

The benchmarks provide a set of indicators (or a yardstick) for examining the progress of the CSEPP. Although some of the benchmarks are not easily quantifiable, most can be measured through quantifiable indicators of progress.

Progress in operational preparedness

Operational preparedness is defined as the emergency systems needed to implement the CSEPP Guidance. It consists of alert and notification systems, communication systems and Emergency Operations Centers.

Alert and Notification

The most important aspect of the CSEPP is notifying populations in time for them to take protective actions. The chief problem is not from a spill of chemical, but an event (such as an explosion) in which the agent would be vaporized and carried off post via a plume. In such cases, the time between the release of chemical agent and the time to take protective action is extremely short. For example, the time frame for a plume reaching people off-post (outside the fence) at Pine Bluff Arsenal is estimated at 8 - 9 minutes.

The approach used in determining the warning systems to be used in the CSEPP was based on the analysis of protective actions, including the maximum exposure reduction, and secondly, the amount of time required by affected populations to complete a protective action. Three alert and notification systems are permitted in the guidance documents to warn residents of an accidental release of chemical agent in the CSEPP. These include:

- stationary sirens with verbal broadcasting abilities,
- dedicated radio systems in certain institutions and facilities, and
- tone alert radios (TARS).

The warnings must be heard in time for all residents at risk to be protected. The combination of indoor and outdoor systems is also recommended to obtain reliable daytime and nighttime notifications.

There is no restraint on communities using the sirens to notify residents of other hazards. For example, one community effectively used CSEPP sirens to warn residents of a tornado. Table 1 shows the status of siren systems. As of September, 1994, all installations had completed the designs for siren placement and issued requests for proposals (RFPs) for installation. Moreover, five sites - Anniston, AL, Newport, IN, Madison County, KY, Pine Bluff, AR, and Toelle, UT, had siren systems in place and operational. Operational means the systems are functioning and meet all CSEPP standards.

Although a variety of Tone Alert Radio (TAR) technologies exist, 3 options were chosen for consideration in CSEPP. These include:

- a special tone alert (TA) unit identified in the CSEPP guidelines;
- a commercial off-the-shelf unit which is activated by the NOAA weather system, and
- a low cost version of the special unit that does not have any of the special features except for a unique activation frequency.

The special TA unit identified in the CSEPP Alert and Notification (A&N) Guidance is designed to have high reliability with low maintenance costs. Among its features are a long life lithium battery, spring clip wall socket attachment device, LED battery condition indicator, 110 volt output, strobe output jack, external antenna jack, LED test status indicator, adjustable message volume, and a visual activation indicator. The special unit's reliability ensures that prompt notification is more likely to be achieved and provides a higher degree of indoor nighttime notification than commercial units. When maintenance costs are factored in, the enhanced technology of the special TA units is clearly more cost effective than commercial units. If the commercial units are not maintained at regular intervals, the effectiveness of the units becomes very questionable. Effectiveness is likely to decrease by 10 to 20 % per year (or greater). The low cost radio has maintenance problems similar to the commercial units but with none of the benefits of the special units. It is therefore not an attractive option. CSEPP issued revised TAR guidance in July that modified the original specification for the TARs. The battery options were made more flexible and the spring clip requirement was eliminated.

Significant progress has been made towards securing TARs for IRZ residences and institutions, special facilities, and other eligible buildings. Seven states have completed demographic surveys estimating the number of units needed to meet CSEPP guidelines. One contract awarded by Madison County, KY called for 10,500 units. Furthermore, bids have been issued for TARs at the Umatilla, Oregon, site by both Oregon and Washington and at Newport, Indiana, site by Indiana . An RFP is expected soon for the Pueblo, Colorado site. The other three CSEPP states are expected to begin work on their TARs in Fiscal Year 95.

Communications

Coordinating emergency response to a chemical event calls for three critical communication capabilities:

- direct, reliable, and redundant communication between the installation's EOC and the off- post EOCs (both primary and alternate) of the affected IRZ counties and states;
- reliable inter jurisdictional EOC communications for all affected off-post areas as well as links with the state emergency services or related agencies; and
- reliable communications between all off-post

EOCs and their field units.

Because emergency information must be transmitted quickly and accurately, the emergency communication system must have both a high reliability factor and redundancy. Dedicated, non-public telephone lines provide an effective means of on-post to off-post communication efforts. However, dedicated lines are often limited by the distances involved and local telephone facilities. In addition, dedicated lines may become inoperative due to weather, line damage, or system overload.

Radio links using dedicated frequencies offer another effective means of communication. A communications network, consisting of redundant telephone and radio systems, provide a critical link between the army installation's EOC and notification point with the EOCs and notification points of all IRZ counties and states. Regardless of whether the telephone or radio system is designated the primary method of communication, the other system must be provided to serve as a backup. Both primary and alternate systems must have high reliability.

On-post to off-post initial notification should be handled in a way that gains the attention of the off-post personnel and provides needed information. This initial notification must go to a facility staffed 24-hours a day and capable of further disseminating the messages and activating resources within the time frames ensuring protection of all the populations at risk. Systems must also provide for timely interagency and inter jurisdictional communications.

Once the off-post coordinating agencies have received the initial information, they must be able to communicate with, activate, and mobilize their respective response units. These include law enforcement agencies, fire departments, emergency medical and rescue units, and other public safety resources as well as governmental, health, school, and other special facility authorities. Communicators must be able to handle information related to chemical emergencies accurately and in a timely manner because of the potential precipitous nature of the hazards. As local emergency plans are updated, internal communication protocols are to be reviewed and modified as needed to assure rapid and accurate information transfer.

As of October 1994 seven out of ten states have operational (full or partial CSEPP compliant) dedicated radio systems in place, and six out of ten states have dedicated telephone systems installed. Half of the states involved have both the dedicated radio and telephone systems in place. Three states have at least one system in place. Two states, delayed by contracting problems, have yet to install either system, but are now progressing towards installation in FY95.

EOCs

Emergency Operations Centers

Emergency Operations Centers are the command and control center for managing an emergency. Last year EOCs met CSEPP guidelines at 4 of the 8 sites. This year an additional 3 sites fully conform to CSEPP guidelines. The remaining site has an excellent EOC which almost conforms to CSEPP guidelines and is in the process of being upgraded. Altogether, CSEPP has provided resources for 14 primary and back up EOCs at the 8 sites. We anticipate upgrading several additional EOCs over the next year. Although most of the work on EOCs has been accomplished at this time, we anticipate further improvements as automation systems are upgraded.

Progress in functional preparedness

Functional Preparedness is defined by those activities necessary to develop and support an effective emergency response. It includes planning training exercises, and public affairs activities.

Training

Because of the unique threat (which is without precedent in the U.S.) and the critical response time frame, training is considered essential to the CSEPP. Some training for the CSEPP was developed for general audiences to address concepts, such as how a plume disperses vapor; while others explain the concepts in the planning guidance documents. Other training is more specific and intended for special audiences, such as emergency responders or members of the medical community. Most of the training includes videos as well as printed material for trainers to use in their jurisdictions. This provides some degree of consistency in the dissemination of the training information across CSEPP sites.

The number of persons trained in CSEPP procedures continues to rise. Has it risen to our expectations? The data are unclear because of the extreme variance among jurisdictions in terms of commitment to the program and in the perception of risk to the community. We have found that the traditional interaction between the installation and the communities (or agencies and the communities) often affects community initiatives for protective actions. In one jurisdiction, the Army installation has been an inherent part of the community for so long and the relations between the community and the installation so cordial that the community is willing to proceed with whatever the installation recommends as protective action for an accident. Consequently, the community has little motivation to engage in any training for an accident. In another instance, a state agency has taken the initiative to organize the CSEPP and the community has taken no role in training or other protective actions.

Since the start of the training sessions, an estimated 12,962 persons have been trained - approximately 4,966 alone between June 1993 and July 1994. Table 2 presents the status of trained personnel in CSEPP. The table does not reflect training that the CSEPP community may have taken for other tasks; the training is only for CSEPP approved programs. The largest trained group is located where the first disposal of munitions is to occur - Tooele, Utah.

Exercise

Initial exercise cycles were completed last year at all 8 sites. A full initial cycle consists of 3 events: a table top exercise, a direction and control exercise, and a full scale exercise. In the past year 6 exercises were conducted with another 5 scheduled before the end of the calendar year. In February 1993, the exercise document was revised, implementing a major "mid–course" correction to expedite development of exercise reports. In July, exercise objectives were revised to clarify the goals of conducting exercises.

Planning

CSEPP specific plans and operating procedures are in place for all States and IRZ counties and for most PAZ counties. Eight states have updated their plans and/or operating procedures since last year. All IRZ counties and most PAZ counties have also updated their plans and/or operating procedures since last year. Further plan and procedure revisions are expected as new guidelines are published.

CONCLUSIONS

The date for final disposal of the munitions has been pushed back several times as that complex program evolves, creating the need to redefine the CSEPP. There have been significant accomplishments as well as setbacks. Activitiessuch as the installation of sirens is well along the way, whereas less success has been achieved in installing an indoor system. Some initiatives have taken time to develop and implement. For example, gaining consensus on guidelines, previously called standards, to ensure all communities potentially exposed to a chemical release are able to protect themselves, has been a slow process.

Communities at risk have not reached the goal of "maximum protection," however, they are much better prepared than at the start of the CSEPP - or even two years ago. The progress in the last year has been greatly accelerated over previous years. Integration into an all-hazard management is the critical next step. At some sites it is being initiated, but it is far from complete. The greatest problem to date in reaching maximum protection is in the slow dissemination of the technology-based systems. The least problematic areas have been in the traditional aspects of emergency management, i.e., in EOC design, communications, exercises, and plan development. Meeting the goal of "maximum protection" at the eight storage sites is not an easy task, but the commitment to maintaining safer communities is one that promises to benefit everyone, even if a chemical agent accident never occurs.

The CSEPP is right on target in regard to the mission statement because the activities of the CSEPP include all phases of hazard mitigation. Furthermore, CSEPP is committed to the Agency goals. CSEPP has many all hazard benefits which already are being realized. Few would disagree that CSEPP has extensively improved and strengthened state and local management capabilities. CSEPP will set a lead for providing rapid response to and recovery from potential disasters. It represents a comprehensive and risk based program which will become one of FEMA's models for revitalizing emergency management in this country.

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Table 1. Siren system status

Site	Design Completed	RFP Initiated	Installation Initiated	Installation Completed	System Operational
APG/MD	7/93	8/93	**10/94**	**12/94**	**3/95**
ANAD/AL	DateUnknown	Date Unknown	7/93	Date Unknown	9/93
BGAD/KY	DateUnknown	Date Unknown	2/94	8/94	10/94
NAAP/IND	7/91	8/92	3/94	9/94	10/94
PBA/AR	10/92	10/93	1/94	Date Unknown	5/94
PUDA/CO	3/94	3/94	?	?	?
TEAD/UT	10/92	10/92	10/93	6/94	6/94
UMDA/OR	5/92	12/93	**10/94**	**11/94**	**5/95**
UMDA/WA	8/94	9/94	**12/94**	**7/95**	**7/95**

- **Bold dates indicate estimated dates for completion of siren installation.**

Table 2. Estimated number of people enrolled in CSEPP related training.

	CSEPP Courses	EMI Courses	Automation Courses	Other Courses	Total Trained
Trained Since 6/93	3086	293	281	1306	4,966
Total Trained	7693	931	487	3851	12,962

Source: FEMA and ORNL, 1994.

THE UNITED STATES' *CHEMICAL SAFETY AND HAZARD INVESTIGATION BOARD*

A NEW INTERNATIONAL RESOURCE
FOR ENHANCING SAFETY IN THE CHEMICAL INDUSTRY

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Washington, D.C.

KEYWORDS: chemical safety, chemical accident, chemical industry, accident investigation, safety information.

ABSTRACT

On November 15, 1990, the United States took a bold step forward to make the world safer for workers and communities. On that day it enacted amendments (Public Law 101-549, 1990) to the United States' Clean Air Act, amongst which was a provision authorizing creation of an unprecedented, independent federal agency, the *Chemical Safety and Hazard Investigation Board* (Board). By their respective actions, the Congress and the President of the United States acknowledged the growing risk that chemicals present and the need to work in partnership with industry to reduce the likelihood and effects of chemical-related accidents. Consistent with its charter to promote chemical safety by conducting independent accident investigations and preparing safety recommendations, the vision of the Board...whose first Chairman was confirmed by Congress on October 6, 1994...is to be the world leader in industrial chemical safety information and services.

The Board's mission is to provide any and all industries that use or otherwise handle chemicals...not just chemical manufacturers...with information and tools to enable identification and mitigation of operational conditions that compromise safety. Congress directed the Board to accomplish its mission by (1) conducting investigations and reporting on findings regarding causes of chemical accidents at fixed facilities as well as "on the road", (2) evaluating the effectiveness of other federal government agencies in preventing industrial chemical accidents, (3) conducting special studies, and (4) developing and communicating recommended actions (based on research and investigative findings) to improve the safety of operations involved in the production, transportation, and industrial handling, use and disposal of chemicals.

The Board's focus extends beyond the United States' borders. Recognizing that chemical accidents may have global effects, Congress encouraged the Board to offer investigative assistance to other countries, both as a means of helping and as a method of learning. Through its international outreach efforts to government and industry, the Board will be better able to ensure its safety research program, professional services and technical information accurately and adequately address the world's chemical safety needs.

This paper details the basis for creation of the Board, its legislated authorities and responsibilities, and its domestic and international role in promoting industrial chemical safety.

NEED FOR THE BOARD

Chemicals are what we must endure for a modern society. While some might deem it desirable to do so, we truly cannot live today without chemicals. They are an integral and ever-increasing part of our complex technological world, making it possible for us to have many of the trappings of the good life we have come to expect and would fight to retain. Yet, as the 1984 catastrophe in Bhopal, India dramatically and tragically demonstrated, those same chemicals are the source of danger to those in the workplace and surrounding locales who are regularly exposed to them. We have seen how their improper use and handling have a chronic impact and exact unacceptable human and economic costs on families, industries, communities, and nations. As a result, we have learned that correcting situations that could lead to disasters and catastrophes is more responsible and less expensive than hoping inevitable accidents will not occur.

In creating the Board, the United States acknowledged the growing hazard that chemicals represent within our worldwide society. It recognized the need to identify and address the causes of the thousands of chemical accidents that occur annually, as well as the need to protect life, property and the environment. from the costly consequences of those accidents. The magnitude of the problem and the challenge facing the Board can best be understood by examining statistics on the number, nature and results of hazardous materials accidents in the United States.

How Pervasive Is The Chemical Hazard?

As of February 1993, the United States Environmental Protection Agency's (EPA) Resource Conservation and Recovery Information System (RCRIS) reported the existence of **278,755 facilities** that generate, transport, treat, store and/or dispose of regulated hazardous waste. At these locations substances exist whose nature and quantities pose significant risk to the workers, general public and environment. As not all dangerous chemicals or wastes or facilities that handle chemicals are regulated, the actual number of locations may be much higher. In addition, according to the United States' National Transportation Safety Board (NTSB), *"about four billion tons of regulated hazardous materials are shipped each year with more than 250,000 shipments of hazardous materials entering into the U.S. transportation system daily"* (NTSB 1992).

How Many Chemical Accidents Occur?

The universe of chemical accidents within the United States cannot now be accurately tallied. No comprehensive, reliable historical records exist. Further, EPA acknowledges that many accidents occurring today at fixed facilities and during transport are not reported to the federal government. This underreporting is documented by several studies (National Environmental Law Center et al. 1994). What is known, however, is that in 1991 the National Response Center received over 16,300 calls reporting the release or potential release of a hazardous material (US EPA 1993). Also, NTSB's statistics indicate that, in 1992, chemicals were involved in 3,500 fatal highway accidents and 6,500 railroad accidents (NTSB 1992).

One study analyzed information contained in EPA's Emergency Response Notification System (ERNS) database. ERNS (even with its significant limitations) is acknowledged to be the largest and most comprehensive United States database of chemical accident notifications, covering both transportation and fixed facility accidents. The study found that from 1988 through 1992 an average of 19 accidents occurred each day…6,900 per year, with more than 34,500 accidents involving toxic chemicals occurring over the five-year period. The study's report emphasized that the findings gravely understated the severity of the United States' chemical accident picture (National Environmental Law Center et al. 1994).

What Human Consequences Result From Chemical Accidents?

Although the absolute numbers vary depending on the source of statistics and period of time examined, there is no doubt about the effects of chemical accidents on human life…year after year, large numbers of people are killed and injured.

> During the years 1988 through 1992, six percent, or 2,070, of the 34,500 accidents that occurred resulted in immediate death, injury and/or evacuation; an average of two chemical-related injuries occurred every day during those five years (National Environmental Law Center et al. 1994).
>
> During the years 1987 through 1991, chemical accidents resulted in 453 deaths and 1,576 injuries at fixed facilities, while transportation accidents involving chemicals claimed 55 lives and injured 1,252 persons (US EPA 1993).
>
> Within a five-year period in the mid-1980's, EPA's Acute Hazard Events database…which contains information only for chemical accidents having acute hazard potential…indicates there were 10,933 such accidents, of which 135 resulted in fatalities, 1,020 resulted in injuries and 500 resulted in evacuations (US EPA 1993).

AUTHORITIES OF THE BOARD

As the Board's legislative history clearly documents, Congress intends the Board to be a powerful voice in the effort to improve the safety of chemical operations.

With only the single prohibition on investigating chemical accidents occurring on waterways, Congress did not restrict the scope of work in which the Board may engage.

> *"The principal role…is to investigate accidents to determine the conditions and circumstances which led up to the event and to identify the cause or causes so that similar events might be prevented. The accidents…to investigate are those which result from…a chemical substance (not limited to the extremely hazardous substances…)…." "…is to investigate accidents resulting from the production, processing, handling or storage of chemical substances causing*

death, serious injury, or substantial property damage (including damage to natural resources)" (Senate Report 1989). *"Substantial damage would include fires, explosions, and other events which cause damages that are very costly to repair or correct...."* (House Report 1990). *"...the phrase "producing, processing, handling or storing an extremely hazardous substance" used throughout this section is to be read in the broadest way to include the transportation of such materials from one site to another." "...may also conduct investigations and studies at sites where...extremely hazardous substances are present, whether or not an accident has occurred when there is evidence of a hazard or potential hazard"* (Senate Report 1989).

Congress made the Board independent in order to ensure it would be able to accomplish its mission.

> *"The independence of the Board in its official duties...is essential for several reasons. First, it is unlikely that an agency charged both with rule-making and investigating functions would be quick to acknowledge that existing requirements were insufficient to prevent an accident. ....Second, the Board is intended as an organizational stimulus to an appropriate amount of regulatory activity by the Environmental Protection Agency in this area"* (Senate Report 1989).

Congress charged the Board to think expansively, and adhere tenaciously to the tenet of objectivity, when conducting investigations.

> *"The Board should take an 'all cause' theory in discharging its investigatory duties. It is not the single, necessary or sufficient cause which is to be the focus of the Board's inquiry, but all circumstances which contributed to the accident...." "It is not the role of the Board to apportion blame or to affix liability;.... Rather, the Board is to identify those actions, omissions, events, and conditions (or combination thereof) which led to the accident or incident for the purpose of recommending modifications to processes, equipment, and procedures to prevent similar accidents or incidents in the future." "...it is not expected that the Board will accuse any party or fix fault. Rather, and to the extent practical, the Board is to give a precise and factual statement of why the event occurred." "It is to be emphasized again that the purpose of the Board's investigation is not to buttress the case for a remedy to those injured or suffering loss by allocating liability, rather it is to provide remedy for the community as a whole by identifying those factors which caused the accident and which may be modified to prevent a recurrence"* (Senate Report 1989).

ROLE OF THE BOARD

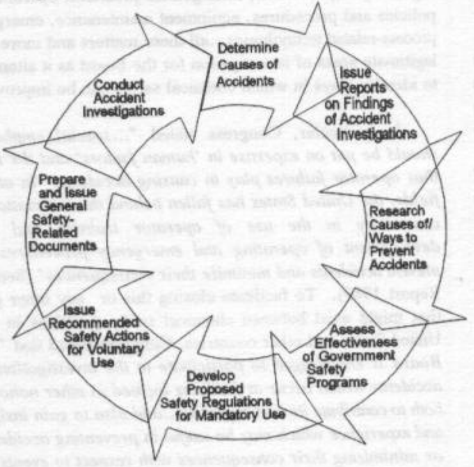
In contrast to the primary *"add-on safety and mitigation"* focus of other government agencies involved with chemical accidents, the Board's complementary emphasis is on encouraging adoption of what is commonly referred to as the *"inherent safety"* approach to accident prevention: preventing a problem by modifying the source of the problem. The Board serves as an independent, investigatory body, examining accidents to determine causes and performing other work designed to help industry reduce the possibility of future accidents and, as a result, the possibility of future disasters or catastrophes. Worker training, regulatory requirements, management practices, operational policies and procedures, equipment maintenance, emerging process-related technologies...all these matters and more are legitimate areas of investigation for the Board as it attempts to identify ways in which chemical safety can be improved.

In particular, Congress stated *"...special emphasis should be put on expertise in 'human factors' and the role that operator failures play in causing accidents. In other fields, the United States has fallen behind the international community in the use of operator training and the development of operating and emergency procedures to prevent accidents and minimize their consequences"* (Senate Report 1989). To facilitate closing this or any other gap that might exist between chemical safety practices in the United States and other countries, Congress stated that *"the Board is encouraged to participate in the investigation of accidents which occur at facilities located in other nations, both to contribute its own expertise...and also to gain insight and experience which may be useful in preventing accidents or minimizing their consequences with respect to events or facilities of a similar type located in the United States"* (Senate Report 1989).

A goal of the Board is to serve as industry's chemical safety research arm, bringing together in a single location and making sense of a vast amount of information that, historically, has been difficult to obtain, comprehend and utilize. As there are tangible economic incentives for companies to improve operational safety, providing them easy access to Board resources is crucial.

Although the Board's primary task is to conduct investigations and report on its findings regarding the cause(s) of chemical accidents, it also has other significant responsibilities. As the federal government's primary information center for documents, data and other intelligence dealing with chemical safety and chemical accidents, it performs research and conducts special studies into the (technological, operational, managerial and other) causes and methods of preventing or reducing the severity of chemical accidents. It prepares and disseminates a wide variety of technical and educational documents: accident reports, safety studies and recommendations, statistical analyses. It performs an oversight role, evaluating the effectiveness of other federal government agencies in preventing industrial chemical accidents and promoting industrial chemical safety. Although not an enforcement agency, it is empowered to develop and communicate recommended mandatory government regulations...for others to promulgate...and voluntary industry actions to improve the safety of operations and minimize recurrence of chemical accidents.

Fig. 1 Chemical Safety Board's Functions



The Board's efforts are designed to enable it to answer a single stakeholder question: ***Where am I vulnerable today and what should I do differently tomorrow to attain the highest level of chemical safety possible within economic, technological and human limitations?***

CONCLUSIONS

Unlike disasters which may have dramatic but short-lived or relatively localized effects, impacts associated with chemical accidents may be long-lived and extremely costly. The Board is mindful of the devastation that can follow a chemical accident, and recognizes it is battling time in its efforts to reduce the number and severity of such accidents. A chemical accident does not just affect employees and locations directly involved with the accident. Chemical releases may render large geographic areas uninhabitable, cause debilitating or life-threatening illnesses and genetic abnormalities in multiple generations of humans and animals, result in wide-spread contamination of food supplies and water, and require the expenditure of millions of public dollars over many years to clean up affected environments and care for affected individuals. In short, social disruption of the over many years to clean up affected environments and care for affected individuals. In short, social disruption of the family unit and community structure may occur, and economic losses, environmental degradation, and deterioration of human health may result.

Causes of chemical accidents are many, complex and interrelated. Regulations, management practices, worker skills and knowledge, training, operating policies and procedures, equipment, technical processes, and the chemical itself may all play a role. Unlike an airplane accident, a chemical accident yields no "black box" holding clues to the final moments preceding the accident. Unlike floods, tornadoes or other natural disasters, chemical accidents occur without warning, although their precursors may be in evidence if but one knows what to look for.

In executing its responsibilities, the Board must wrestle with incomplete and sometimes inaccurate historical accident data, confusing and often contradictory regulatory requirements, and a business world comprised more of smaller companies with limited resources than larger ones with unlimited resources. Given the fact that chemicals will not disappear from our lives, the Board realizes we must make their use safer for all. By understanding what could go wrong in the future, as well as what has gone wrong in the past, steps can be taken to identify and correct systemic weaknesses leading to the thousands of chemical accidents that occur annually. The Board's mission is to work in concert with industry, labor and government to help prevent those accidents by determining and addressing their causes...causes which, if not addressed, could result in another Bhopal catastrophe.

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BIOGRAPHY

Paul L. Hill, Jr. is the Chairman and a Member of the United States' Chemical Safety and Hazard Investigation Board. Prior to accepting the President of the United States' offer of this position and being unanimously confirmed for the position by the full United States Senate, he served as the President and Chief Executive Officer of the National Institute for Chemical Studies (NICS), a non-profit public interest research group focusing on public education, emergency preparedness, community safety, pollution prevention, hazard assessment and risk communication regarding hazardous chemicals. Dr. Hill received his Bachelor's and Master's degrees from Marshall University, and a Ph.D. in biology and systems management from the University of Louisville. In addition to working with private and public organizations involved with the environment, Dr. Hill has served as Deputy Administrator for Environmental and Regulatory Affairs in West Virginia's Department of Natural Resources where he authored environmental regulations and legislation. Dr. Hill, who has carried his message of collaboration between industry and government and the public to major metropolitan centers throughout the United States and to Europe, is a frequent speaker before national forums and symposia. His views on chemical industry policy and related issues have been presented in television, radio and newspaper interviews, and his writings and positions on environmental issues have been carried in scientific journals, national trade magazines, government publications and conference proceedings.

Chemical Stockpile Emergency Preparedness Program Issues II: Utilization of Computer Tools

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A MICROCOMPUTER BASED TRAFFIC EVACUATION MODELING SYSTEM FOR EMERGENCY PLANNING APPLICATION

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KEYWORDS: Emergency Evacuation Planning, Computer Simulation, Traffic Model, Regional Evacuation, OREMS, Graphical User Interface

ABSTRACT

Vehicular evacuation is one of the major and often preferred protective action options available for emergency management in a real or anticipated disaster. Computer simulation models of evacuation traffic flow are used to estimate the time required for the affected populations to evacuate to safer areas, to evaluate effectiveness of vehicular evacuations as a protective action option, and to develop comprehensive evacuation plans when required. Following a review of the past efforts to simulate traffic flow during emergency evacuations, an overview of the key features in Version 2.0 of the Oak Ridge Evacuation Modeling System (OREMS) are presented in this paper. OREMS is a microcomputer-based model developed to simulate traffic flow during regional emergency evacuations. OREMS integrates a state-of-the-art dynamic traffic flow and simulation model with advanced data editing and output display programs operating under a MS-Windows environment.

INTRODUCTION

The U.S. Army stockpiles unitary chemical weapons, both as bulk chemicals and as munitions, at eight major sites in the United States. The continued storage and disposal of the chemical stockpile has the potential for accidental releases of toxic gases that could escape the installation boundaries and pose a threat to the civilian population in the vicinity. The U.S. Army, in conjunction with the Federal Emergency Management Agency (FEMA) and other federal agencies, is committed to implementing an emergency preparedness program that will significantly reduce the adverse effects of accidental releases from the chemical stockpile (Carnes *et al.* 1989).

Evacuation is a preferred protective action option available for emergency management in times of threat to the general public in all types of hazard, when enough time exists for successful implementation. For the Chemical Stockpile Emergency Preparedness Program (CSEPP), evacuation by itself or in conjunction with other protective actions (e.g., respiratory protection) is being considered as a viable option to reduce the risk of adverse health effects from accidents involving the chemical agent stockpile.

As part of a broad effort to provide technical assistance to FEMA and the U. S. ARMY for the CSEPP program, Oak Ridge National Laboratory (ORNL) has been developing a microcomputer-based software for analysis, evaluation, and development of evacuation plans for the eight CSEPP sites. This package is referred to as the Oak Ridge Evacuation Modeling System (OREMS). Following a review of the past efforts on evacuation traffic flow modeling, this paper describes the key features of the soon to be released Version 2.0 of OREMS.

EVACUATION MODELING: PREVIOUS EFFORTS

The use of traffic flow models in evacuation planning is a widely accepted practice in the United States and is also becoming popular in other first and second world countries. These analytical or simulation models are used to estimate the time required for the affected populations to evacuate to safer areas and to evaluate the effectiveness of vehicular evacuations as a protective action option. These analyses are an integral part of evacuation planning in many situations and are often performed to meet certain regulatory requirements (e.g. relicensing of nuclear power plants).

A range of approaches have been used in developing evacuation traffic flow models. Basically, the modeling involves estimating the number of vehicles that will evacuate from different zones of the affected area during the response period (the demand), estimating the evacuation routes, and comparing the traffic demand with the highway network capacity. One of the simplest approaches is an aggregation procedure which estimates the number of evacuating vehicles (load) from a given region or zone, assigns the vehicle load to routes, and estimates the evacuation time by dividing the number of vehicles by estimated roadway capacity (see for example, Stone 1983). Such analyses can produce meaningful results, when populations are small and the roadway systems are not complex. However, for large population evacuations on a regional basis, simplified analyses such as these are neither feasible nor meaningful (Urbanik and Jamison 1992).

On the other extreme are the very sophisticated computer models and traffic modeling approaches that were developed in the early 1980's. One of the early efforts was the CLEAR (for Calculates Logical Evacuation and Response) model developed for the Nuclear Regulatory Commission (NRC). CLEAR simulates vehicle departure and movement on a roadway network, given the most likely subset of evacuation routes (McLean *et al.* 1983). The CLEAR model makes several simplifying assumptions, including modeling of individual vehicles only on the primary road network. More detailed and realistic simulation models for evacuation traffic flow are the I-DYNEV, NETVAC1, EVACD, and MASSVAC computer programs (Southworth 1991). Most of these models incorporate mobilization time, destination selection, and route choice behavior in the simulation procedure and each produces an estimate of the evacuation time (time to clear the area), as well as, traffic performance in the represented network.

I-DYNEV (for Interactive Dynamic Network Evacuation model) is perhaps the most sophisticated and most used evacuation planning model. I-DYNEV was developed by KLD Associates, as part of FEMA's Integrated Emergency Management Information System (IEMIS), for application to nuclear power plant emergencies (Jaske 1986). I-DYNEV combines a static, equilibrium traffic assignment model with a macroscopic simulation model, both of which were adopted from the TRAFLO family of simulation models developed for the Federal Highway Administration (Lieberman *et al.* 1983). A trip distribution model was later integrated with the traffic assignment model (Lieberman 1987). I-DYNEV has been used to estimate evacuation times and develop evacuation plans for several nuclear power plants licensees and other natural and technological hazards (Urbanik *et al.* 1988).

Despite the progress made since the early 1980's, however, a great deal of additional research and development needs to be done before the existing evacuation traffic models can be used very effectively for the analysis, evaluation, and development of evacuation time estimates, routing strategies, and overall evacuation plans. The ability to realistically replicate a likely evacuation event and provide useful analysis tools poses many technical challenges. The lack of proper data and models, complexities in models, interaction among models, transportation considerations for all affected populations, the need to analyze a multitude of scenarios, large databases, and various other considerations make the task extremely complicated and difficult.

A major problem with these models has been the lack of realistic representation of driver behavior with respect to departure delays, destination selection, and route selection. In addition, the existing models lack user-friendly interfaces for data entry and manipulation, output analyses, and database management. The user interface for even the sophisticated models, such as I-DYNEV, are primitive by today's standards in microcomputer-based software. The task of creating a data file, developing evacuation scenarios, explaining the modeling concepts to emergency planners, and interpreting the output data remains a tedious and difficult task (Rathi *et al.* 1993).

Another major deficiency of the research in this area is the lack of comparative studies and model validation. While the I-DYNEV model has been used in numerous applications, very little is known about the model logic and the accuracy of its results. Aside from a small benchmark study, conducted for Pacific Northwest Laboratory by the Texas Transportation Institute (Urbanik *et al.* 1988), very little information exists in the open literature about the validation and "realism" of the model.

Finally, considerable work must still be done before "real time" decision support systems can be developed. The evacuation traffic simulation models are currently being embedded within emergency management information systems, such as FEMIS. However, much work must still be done before these models can truly be used in an "on -line" fashion for management of emergencies in real-time.

THE OAK RIDGE EVACUATION MODELING SYSTEM (OREMS)

In response to the various difficulties encountered with the I-DYNEV model during preliminary evacuation studies associated with the CSEPP program (Rathi *et al.* 1993) and to develop a non-proprietary evacuation model for use by various state and local emergency management planning offices, FEMA and the U.S. Army are sponsoring the development of a microcomputer-based evacuation modeling system at ORNL. This system is popularly known as OREMS (for Oak Ridge Evacuation Modeling System).

OREMS is an integrated software system which performs three operations: input data file and management, simulation analysis, and output displays. The following section provides a brief description of the major features of OREMS.

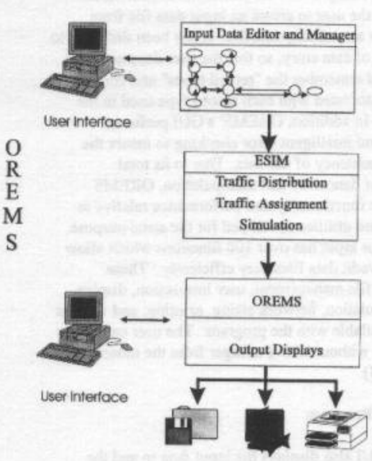

Figure 1. OREMS Structure from the User's Guide

ESIM Model

ESIM (for Evacuation SIMulations) is the analytical core of OREMS. ESIM is a rather complex FORTRAN-based program that simulates the traffic conditions over a transportation network as an evacuation progresses. The ESIM model combines a trip distribution and traffic assignment model with a detailed traffic flow simulation model. Through traffic distribution and assignment, ESIM determines the destinations selected by evacuees and the routes taken to reach the selected destinations. It also performs a detailed simulation of traffic operations on the evacuation network, given these projected flows and routes under prevailing roadway and traffic conditions. This simulation allows the analyst to estimate service rates in the evacuation network by location and by time; identify performance characteristics of traffic; identify bottlenecks; and estimate evacuation times across various categories (link, sector, or region specific estimates by time). The algorithms used in ESIM's traffic assignment and simulation models are based on techniques that have resulted from years of research sponsored by the Federal Highway Administration. The three submodels of the ESIM model are described next.

ESIM's Simulation Model - ESIM's simulation model is an adaptation of the NETFLO II and FREFLO models of the TRAFLO family of macroscopic simulation models (FHWA 1991). The term macroscopic means that the model simulates the flow of traffic in some aggregate fashion rather than the movement of individual vehicles in a microscopic fashion. The vehicular movements on surface streets are modeled using the NETFLO II logic and that on the freeway sections are based on the FREFLO logic.

The traffic stream in the NETFLO II model is represented in the form of movement-specific statistical histograms. The length of time during which a simulation is performed is split up into a series of Time Periods (TP) with each TP being further subdivided into a series of Time Intervals (TI). Traffic congestion and spillbacks are treated explicitly in the simulation model. Vehicles can move on to the receiving link only if there is space available to accommodate the vehicles that want to enter that link. In this way queues develop. The effects of traffic control measures (i.e., signals, STOP and YIELD signs) are also simulated at every intersection.

In FREFLO, the traffic is represented as aggregate measures such as the flow rate, space mean speed, and density. The freeway itself is modeled as a set of segments each with its own attributes representing the aggregate measures of traffic flow. Traffic flow is assumed to be homogeneous within a section. The model logic primarily consists of a pair of dynamic equations expressing the conversation of vehicles and the dynamics of speed behavior. The model accommodates freeway-to-freeway connectors involving merge/diverge points and on/off-ramp flows.

ESIM's Trip Distribution Model - The destination selection models are commonly referred to as the trip distribution models by transportation planners/analysts. Simply stated, trip distribution is the process by which the origin and destination ends of a trip are defined. In the case of evacuation modeling, the origins of trips are determined based on the location of the populations (in various categories) at the time of the emergency. The destinations selected by evacuees are modelled in one of the three ways:

1) evacuees will exit via pre-specified destinations based on an established evacuation plan;
2) evacuees will exit the 'at-risk area' by heading for the nearest destination in terms of distance or time; and
3) evacuees will exit via the closest destination in terms of time or distance, on the basis of traffic conditions at their time of departure.

ESIM allows the user to specify the destinations associated with each traffic origin. As an option, the model performs a trip distribution to determine the destinations for an origin. The destination selection (trip distribution) is based on a hybrid of the three modeling options described above.

ESIM's Traffic Assignment Model - Route selection models are used to approximate the path selected by evacuees (i.e., evacuation routes). The process of assigning paths to the traffic flow is referred to as traffic assignment in transportation planning. The basic methodology in traditional traffic assignment is to determine a logical path between an origin and a destination under given traffic conditions, based on system or user optimal travel behavior.

ESIM's traffic assignment model is an equilibrium assignment model which attempts to find a user optimal solution. The term equilibrium is characterized by Wardrop's famous first principle (Wardrop 1952) which states that "the journey times on all routes actually used are equal, and less than those which would be experienced by a single vehicle on any unused route." For this user-optimal assignment principle, an equivalent minimization problem can be formulated. The solution to this problem, thus, produces the traffic pattern which satisfies Wardrop's first principle. The traffic assignment model of ESIM and TRAF is an elaboration of the equilibrium traffic assignment model, TRAFFIC, developed by Nguyen (Nguyen 1975).

TRAFFIC is still one of the best traffic assignment models. One of the key inputs to traffic assignment models is the estimate of the capacity of highway segments. Most, if not all, other traffic assignment models employ constant, estimated values of link capacities. It is well known that link capacity is a function of many factors including the unknown turn volumes on all approaches serviced by an intersection. A very comprehensive capacity estimation model has been included in the TRAF and thus ESIM models. This model produces, through iterations, accurate estimates of service rates (capacities) for each link of the highway network by taking into account the assigned volumes and type of traffic control at each intersection. The solution procedure used in the capacity model is rapid, accurate, and unconditionally convergent.

Input Data Manager

Simulation models by their very nature are data intensive and ESIM is no exception. The physical highway environment, which must be specified as input data to use the ESIM model, includes the network geometry, traffic inflow, turn percentages, and traffic control. The user is required to enter detailed information on these items (e.g., lane channelization, signal control data), much of which also varies by time. In addition, several other input parameters must be specified for run control or to change the default values embedded in the models. The smallest ESIM input data file representing an isolated intersection consists of over 50 lines of 80-column data. The large data files, on the other hand, can consist of hundreds of lines of data. Also, the data structure is such that one must adhere to very strict formats while utilizing many numeric codes. Preparing the data files needed to run ESIM for even small networks can be a very tedious and time consuming activity.

OREMS is a graphical user interface (GUI) which was developed to greatly simplify the task of creating the data base (or data files) necessary to use the ESIM simulation model. This GUI allows the user to create an input data file from scratch or modify an existing data file. It has been designed to simplify the task of data entry, so that the user does not have to understand and remember the "record types" and countless numeric codes associated with each record type used in the ESIM data files. In addition, OREMS' s GUI performs comprehensive and intelligent error checking to insure the accuracy and consistency of the data. Due to its total graphical mode of data entry and manipulation, OREMS provides superior functionality and performance relative to other programs and utilities developed for the same purpose. OREMS's GUI for input has over 100 functions which allow the user to create/edit data files very efficiently. These functions handle file management, user interaction, display, data entry/manipulation, network sizing, printing, and various other options available with the program. The user can create or edit a data file without lifting a finger from the mouse (Rathi *et al.* 1993).

Output Display Program

OREMS's GUI also displays the input data to and the results produced by the ESIM evacuation simulation model. The data produced by the ESIM simulation model allows the user to analyze traffic conditions during a regional population evacuation. The model produces data on a variety of measures of effectiveness at user-specified time intervals. The statistics are provided for individual links, as well as, for the entire network in a summary format. These data are provided for each link and are also aggregated over the entire network.

Because of the detail of the output data, one could expend considerable time and energy trying to properly interpret the model output to derive statistics of interest from the output files created by ESIM. Typically these output files are several hundred pages of computer printout. The output is in the form of statistics which are hard to visualize even for the most competent and experienced users. Furthermore, the output shows a few obvious statistics on the traffic conditions and the progress of evacuation for the entire area; it requires considerable additional computation to obtain sector- or area-specific statistics or information on bottlenecks in the transportation network.

The post-processor component of OREMS has been designed not only as a utility for analyzing the simulation output, but also to assist the user with evacuation planning. This GUI includes a graphical representation of the simulated traffic conditions for a scenario and displays the "hot spots" in the network, area-specific statistics, and other useful information with a few clicks of the mouse.

Capabilities of OREMS

OREMS is designed to allow the user to perform comprehensive evacuation planning studies; including estimates of evacuation times, development of traffic management and control strategies, identification of evacuation routes, identification of traffic control points, and other elements of an evacuation plan. OREMS can be used to estimate evacuation time and to develop evacuation plans for different events or scenarios (e.g., good vs. bad weather conditions, day vs. nighttime evacuations) for user-defined spatial boundaries. OREMS allows the user to experiment with alternate routes, destinations, traffic control and management, and evacuee response rates. For a given situation, OREMS can help the planner identify the evacuation or clearance times, traffic operational characteristics (e.g., average speed), bottlenecks, and other information necessary to develop effective evacuation plans.

All of the above information can be obtained for a given section of highway, an area within the network, a sector/ring, or at any other level of spatial aggregation. Detailed information on the traffic's operational characteristics can also be obtained at user-specified time intervals between the beginning and end ("clearing") of an evacuation.

APPLICATION OF OREMS IN EVACUATION STUDIES

The first step in evacuation planning and analysis, of course, is the delineation of the emergency planning zones. A three-zone concept for the application of evacuation and other protective action strategies is commonly utilized in the planning process. These zones are: Immediate Response Zone (IRZ), which is the area closest to the point source of the potential disaster, where prompt and effective response is most critical; the Protective Action Zone (PAZ) is an area which is slightly farther away, but still under a potential threat depending upon the type of accident and weather condition; and the Precautionary Zone (PZ) is the outermost boundary beyond which no adverse effect can be expected as a result of the disaster and therefore does not require any significant pre-event planning. For a given area, the specific zonal boundaries are determined on the basis of political, human, and topological factors, with spatial and temporal distribution of the hazard as the most important consideration.

Having determined the IRZ, PAZ, and PZ boundaries, an accurate and reasonably detailed representation of the highway network within these zones is needed to estimate evacuation times and to develop evacuation plans using OREMS. In addition, the following information is required:

a) estimate of traffic demand (number of evacuees and vehicles by location);
b) trip generation time (timing of people's response to the perceived emergency by location);
c) destination and route selection by evacuees; and
d) capacity of the highway network.

Capacity is defined as the maximum number of vehicles that can pass on a given section of highway, in one direction, during a given time period under prevailing roadway and traffic conditions.

Using the information in items (a) and (b) as input to a reasonably detailed description of the highway infrastructure, OREMS can be used to generate the information required in items (c) and (d). The traffic assignment/distribution model of ESIM determines the destination selected by evacuees and the route taken to reach the selected destinations. The simulation model component of ESIM performs a detailed simulation of traffic operations on the evacuation network, given these projected flows and routes under prevailing roadway and traffic conditions. This simulation allows the analyst to estimate service rates in the evacuation network by location and by time, identify performance characteristics of traffic, bottlenecks, and estimate evacuation times across various categories (link-, area- or network-specific estimates by time). The user can specify the origin-destination flows rather than using the traffic distribution model. Typically, the OREMS model has to be used in an iterative manner to obtain the best estimate of evacuation time. Iterations are required not only when experimenting with alternate control strategies, but also to accommodate some limitations of the traffic model.

HARDWARE AND SOFTWARE REQUIREMENTS

The first release of OREMS works for IBM compatible microcomputers under the DOS 5.0 or later versions of the operating system. The upcoming Version 2.0 of OREMS is being developed to work under the MSWindows operating systems on IBM compatible microcomputer with an 80386 or higher preprocessor. The memory requirement is at least 8 MB of RAM. The programs and data for OREMS will need 20 MB of hard disk space to run efficiently.

AVAILABILITY AND WORK IN PROGRESS

OREMS is being developed by the Center for Transportation Analysis in the Energy Division of the Oak Ridge National Laboratory through funding from the Federal Emergency Management Agency (FEMA) and the US Department of the Army, under the Chemical Stockpile Emergency Management Program (CSEPP). Version 1.0 of the OREMS has been distributed to over 30 users since March 1994. Version 2.0 (Beta) is expected to be made available to interested users by spring/summer 1995.

In its current form, OREMS is more user-friendly than I-DYNEV and also a better traffic model. However, much work still has to be done to make it a realistic traffic simulation model, to make the software more user-friendly and versatile, to integrate the model with other analysis tools, such as a plume dispersion model, and to improve its computational efficiency.

Work is now in progress to:

- test and debug OREMS;
- improve user interfaces;
- experiment with microscopic simulation models;
- integrate traffic simulation, assignment and distribution models; and
- integrate the model with other planning models and PADRE;

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ANALYSIS AND EVALUATION OF EMERGENCY RESPONSE USING PROJECT MANAGEMENT AND SIMULATION TECHNIQUES

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ABSTRACT

This article describes how emergency response capabilities can be analyzed and evaluated using project management and simulation techniques. This evaluation approach is contrasted with traditional exercise-based evaluation strategies. Project and simulation models of response tasks are shown to be valuable tools for analyzing response times and variability in response times.

Project models are relatively easy to develop and provide revealing information on the interactions of the various players in the emergency response system, but they are limited because they are based on point estimation. The development of simulation models is somewhat more involved, but because the models use probability distributions rather than point estimates, they yield a more accurate representation of the potential behavior of the emergency response system.

These ideas and techniques were developed through application in the U.S. Army Chemical Stockpile Emergency Preparedness Program (CSEPP).

INTRODUCTION

Innovative Emergency Management, Inc. (IEM), has been providing plan evaluation support to the U.S. Army Chemical Stockpile Emergency Preparedness Program (CSEPP). The goal of CSEPP is the mitigation of the effects of any accident at the U.S. Army's eight mainland chemical weapons stockpile sites. The specific work discussed in this paper involves an effort to integrate the emergency plans of one of the Army stockpile installations with the plans of the state and the three closest counties.

An emergency response can be evaluated in terms of its speed, quality, and cost. However, these metrics only have meaning when analyzing the capability of an emergency response to support the response's ultimate goal: namely, the protection of life and property. Thus, emergency plans should be evaluated on how well and how quickly this goal is reached.

In this paper, we focus on the evaluation of response time, because speed is the easiest of the metrics to capture. Also, for applications with fast-moving hazards, such as chemical accidents, speed is often the most critical dimension.

In addition to the average speed of a response, consideration should also be given to the variability in response time. Variability in an emergency response is directly related to plan robustness. A plan is robust if it can effectively and efficiently handle a wide variety of operating conditions. The reduction of variability in emergency response is an important goal. In a response, a large number of complex, highly interrelated tasks must be performed, and unanticipated situations are almost guaranteed to arise. In such an environment, the ability of the response plans and procedures to handle non-ideal situations is of great concern. Improving plan robustness leads to a more easily managed emergency, and greater confidence in emergency responders.

To analyze the response time, two models of the emergency response processes were created: a project model and a simulation model. Both models accurately reflect actions that would be taken in a true emergency. The models focus on all the individual tasks necessary during a response, as well as their interrelationships. The project model uses discrete point estimates for all response task times, whereas the simulation model improves the realism of the analysis by defining a probability distribution for the time required for each response task.

The models were created through analysis of written plans and extensive interviews with local emergency responders. In addition, the models were verified and corrected, as much as possible, through monitoring of response exercises. This article presents examples of the modeling approach; however, to respect client confidentiality, the examples are fictional and serve only to illustrate the process.

The response models are valuable because they:

- focus on critical tasks and their interdependencies.
- allow rapid "what if" analysis.
- clearly document all response tasks and procedures.
- allow evaluation of response capability by focusing on the goal of response.

PROJECT MODEL

Using commercial, off-the-shelf project management software, we placed emergency response on a project timeline, scheduling the actions of response agencies during a chemical emergency. The technique allows emergency responders to see how their activities impact the rest of the response infrastructure. All dependencies between response tasks are defined explicitly, so that the contribution of each response position to the overall response is shown. The model also clearly identifies critical response tasks that constrain the time required to achieve the ultimate goal of the response.

The finished model consisted of nearly 400 tasks. Figure 1 illustrates the model using a small subset of these tasks. (The figures are at the end of the paper.) The figure shows the county response starting with initial notification and continuing through to activation of the sirens.

The first task, "Notify Staff," takes 12 minutes and starts immediately after the initial notification from the Army. Once the emergency staff have been notified, two tasks proceed simultaneously. The elected official reviews and approves the recommended protective actions, while other staff prepare appropriate siren messages. These tasks are modeled to take 20 minutes and 7 minutes respectively. Once both these tasks are completed, the sirens can be activated.

In this example, the county response takes a total of 47 minutes (12+20+15). Notice that, although activation of the sirens requires both the approval of the elected official and the preparation of siren messages, only the approval delays the activation of the sirens. This analysis suggests that all tasks are time critical except the preparation of siren messages, and hence that improvement efforts should focus on reducing the time needed for these critical tasks rather than reducing the message preparation time.

Project models provide a valuable analysis tool for evaluating response timeliness and the relationships between the parts of the response system. However, they have some limitations. Most significantly, project models do not reflect the variability inherent in an emergency response. One consequence of this drawback is that the models tend to be optimistic. The models are created largely through site personnel input. In our experience, when estimating the time required for specific response tasks, site personnel typically assume no unexpected circumstance will arise to foil their plans. For each individual task, this time estimate may be reasonable, but considering the large number of interrelated tasks performed during an emergency response, it is likely that some task(s) will take longer than expected. For a more detailed analysis – one that allows variability in task times – a simulation model is required.

SIMULATION MODEL

Simulation models were created using commercial, off-the-shelf spreadsheet and simulation software. For each task in the project model, we defined the range of possible response times and a probability function. The amount of variability introduced depended on the nature of the task. Allowing for variability increases the complexity of the model, but also improves the realism. The simulation model quantifies the variability in overall response times. Due to the variability in individual response tasks, the individual tasks that are time critical in any given response may change. As a result, the simulation model provides a broader and more realistic analysis of the current response's capability.

The finished simulation model contains approximately 50 of the most critical response tasks. Figure 2 illustrates how the response tasks used in Figure 1 may be modeled when variability is added. Notice that now each task time can vary. The plots by each task represent the probability density function (pdf) for the task time. The vertical line in each pdf shows the hypothetical response time for each task from one run of the simulation model.

Notification of staff takes between 10 and 20 minutes. Since little information was available regarding what time was most likely, a uniform distribution was used to model the variability in this task.

As in the project model, once the staff are notified two other tasks can be performed simultaneously. Approval by the elected official takes between 15 and 25 minutes. Since this task was fairly predictable and averaged 20 minutes, the variability inherent in this task is modeled with a normal distribution. The time required to prepare a siren message, on the other hand, has a large possible range of 4 to 45 minutes. In most cases, a fairly small amount of time is required because a prescripted message can be used. However, if the accident scenario does not fit the conditions described in the message library, a new message must be drafted which may take a significant amount of time. The gamma distribution models this type of situation very well.

Finally, the time required to activate the sirens is modeled as the sum of two normal distributions. The time required to activate the sirens averages either 15 minutes or 25 minutes depending on whether or not the primary siren activation system functions as intended.

Typically, preparing siren messages takes little time. However, if new messages need to be drafted, as modeled in Figure 2, preparing the message may take longer than the approval by the elected official. If this occurs, the critical path changes, since now preparation of messages now constrains the overall response. This example illustrates the advantages of the simulation model.

In building simulation models the tendency to make overly optimistic estimates for task times can be countered. In our experience, interviewees typically are able to offer reasonable estimates of the range of possible response times for individual tasks. For each task there is usually an easily determined minimum amount of time required that must be greater than zero. The maximum time required is more difficult to determine since long response times, due to special circumstances, are comparatively rare. However, by questioning the underlying assumptions, such as the assumption that primary response personnel will be available, an estimate of the maximum time can be obtained.

In this exercise it is important not to consider very unlikely events, but rather to focus on realistic conditions. Appropriate pdfs are typically right-tailed (like the "Prepare Siren Message" task in Figure 2), or are truncated on the left side. In any individual run of the simulation model, most tasks will have durations near the optimistic times used in the project model. However, due to special circumstances, some tasks may take significantly longer. As illustrated through Figure 2, this analysis can reveal useful information about the robustness of the response and the impact of unexpected delays in certain parts of the response.

The simulation model also allows time distributions to be correlated. For example, in the simulation model IEM created for CSEPP the time required to analyze the hazard is negatively correlated with the probability that the primary hazard analyst is available. This reflects the reality that alternate hazard analysts are not as familiar with the process, and typically take longer to analyze a hazard.

EVALUATING RESPONSE DIRECTLY AGAINST A HAZARD

To further evaluate the response capability, the emergency response models were combined with an analysis of the response of the civilian population, through either evacuation or in-place sheltering, and the progress of the hazard itself.

In our application, evacuation time estimates and in-place sheltering time estimates (the only two protective action decisions considered in CSEPP) were already available, and an analysis of the hazard itself was possible through the use of a chemical dispersion model. Running the dispersion model repeatedly with various combinations of credible accidents and realistic weather conditions created a profile of the hazard. In this way, the time necessary to protect the population, namely the Army and county response times plus the protective action implementation time, can be directly compared with hazard arrival times. From this comparison, it is possible to gauge under which accident scenarios the emergency response is likely to be sufficiently rapid.

COMPARISON WITH TRADITIONAL EVALUATION OF EMERGENCY PLANS

Traditionally, emergency plans are evaluated in a two step process. First, the plans are judged by higher authorities based on a thorough perusal of the plan, but not based on any demonstration of the plan's execution in a disaster environment. Second, response exercises are conducted.

Exercises place emphasis on achieving tasks in a manner consistent with an organization's formal emergency plans. Conformance to plan specifications is regarded as proof that an organization is fit to respond to disaster, since the plan has been approved by a higher authority. During this evaluation, each function in the response organization is considered separately, without evaluating how that function supports the overall response.

In the traditional analysis of plans, the ability to respond is never directly compared to the exigencies of disaster, and the ability of the response infrastructure as a whole system is never evaluated. Rather, each individual role in the emergency is evaluated against the written plan. This way, the contribution of each role to the overall mission – to protect lives and property – can too easily be forgotten. As such, some aspects of an emergency are not given appropriate emphasis by planners and plan evaluators.

In contrast, project and simulation models emphasize the need for a timely response to disaster. Success of a plan's execution is determined based on hypothetical lives saved, rather than conformance to the written plan. Furthermore, each function in the response organization is not assessed in isolation, but evaluated based on its contribution to the overall response goals.

CONCLUSIONS

Project and simulation models enable emergency managers to benchmark their capability against their organizational mission, which is to protect lives and property, instead of against the formal specifications of a written plan. Under traditional plan evaluation, there is no way to tell how one person's actions are dependent on others, or how one person's actions enable others to act. However, using project management and simulation techniques, planners can see how each aspect of response impacts the saving of life and welfare through the identification of response bottlenecks and critical response tasks. Planners can also gauge the ability of their plans to address changing operating conditions, and how changes in their plans improve response times. Since the actions of civilian populations are incorporated into the model, any improvement can be expressed in terms of saved lives.

These modeling techniques cannot supplant exercises as a tool for evaluating plans; exercises still provide uniquely valuable insight into the implementation of a plan. However, the use of project management and simulation can supplement traditional evaluation to improve the timeliness and robustness of a response. In addition, these techniques can be used effectively at a fraction of the cost of conducting an exercise.

BIOGRAPHY

Innovative Emergency Management, Inc. (IEM), is a research-based corporation specializing in emergency management and automation support. The company's expertise lies is five critical areas: emergency planning, computer services, management consulting, data and documentation services, and training. IEM has offices in Baton Rouge, Louisiana, and Salt Lake City, Utah.

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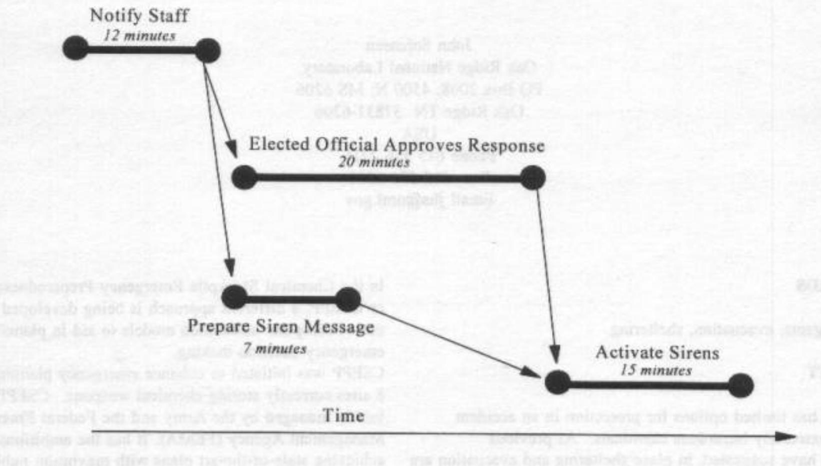

FIGURE 1: PROJECT-BASED RESPONSE MODEL

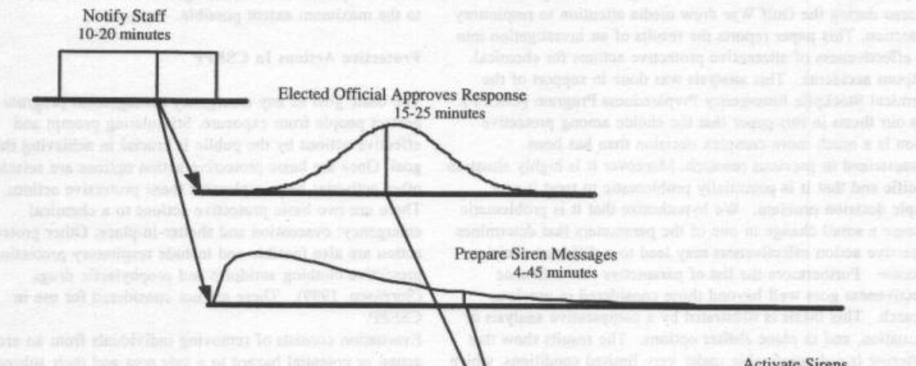

FIGURE 2: SIMULATION-BASED RESPONSE MODEL

PROTECTIVE ACTIONS AND CSEPP: CAN WE SHELTER IN PLACE?

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KEYWORDS

chemical agents, evacuation, sheltering.

ABSTRACT

The public has limited options for protection in an accident involving extremely hazardous chemicals. As previous researchers have suggested, in place sheltering and evacuation are potential options for population protection from a toxic vapor plume. In addition, more attention is being given to several forms of respiratory protection. At least two U. S. companies are marketing respirator devices designed for the general public. Of course European companies have marketed such devices for the past decade. Moreover , the use of gas masks by Israeli citizens during the Gulf War drew media attention to respiratory protection. This paper reports the results of an investigation into the effectiveness of alternative protective actions for chemical weapons accidents. This analysis was done in support of the Chemical Stockpile Emergency Preparedness Program (CSEPP). It is our thesis in this paper that the choice among protective action is a much more complex decision than has been characterized in previous research. Moreover it is highly situation specific and that it is potentially problematic to treat it as a simple decision problem. We hypothesize that it is problematic because a small change in one of the parameters that determines protective action effectiveness may lead to a different decision outcome. Furthermore the list of parameters that influence effectiveness goes well beyond those considered in previous research. This thesis is illustrated by a comparative analysis of evacuation, and in place shelter options. The results show that sheltering is only preferable under very limited conditions, which will be difficult to predict at the time of the emergency.

INTRODUCTION

One of the hottest topics in the area of Hazardous Materials planning over the past several years is whether it is better for people to shelter in place (button-up, in some locales) or to evacuate when confronted with a vapor hazard. A number of guides are available to planners which discuss some of the principles behind planning for protective action decision making. In the Chemical Stockpile Emergency Preparedness Program or CSEPP, a different approach is being developed -- the use of computer simulation models to aid in planning and emergency decision making.

CSEPP was initiated to enhance emergency planning at the 8 sites currently storing chemical weapons. CSEPP is jointly managed by the Army and the Federal Emergency Management Agency (FEMA). It has the ambitious goal of achieving state-of-the-art plans with maximum public protection. It grew out of the Chemical Stockpile Disposal Program (CSDP) which is mandated by Public Law 99-145. The law requires destruction in a manner that maximizes the health and safety of the public. As a result it is critical to plan for accidents in a manner that reduces human exposure to chemical agents should a release occur to the maximum extent possible.

Protective Actions In CSEPP

The basic goal of any emergency management program is to protect people from exposure. Stimulating prompt and effective actions by the public is crucial in achieving this goal. Once the basic protective action options are selected, other activities help implement those protective actions. There are two basic protective actions to a chemical emergency: evacuation and shelter-in-place. Other protective action are also feasible and include respiratory protection, protective clothing antidotes and prophylactic drugs (Sorensen, 1989). These are not considered for use in CSEPP.

Evacuation consists of removing individuals from an area of actual or potential hazard to a safe area and their subsequent return after reentry is approved. It is the most effective of all protective actions provided it is completed before the arrival of the toxic plume. Evacuation may be precautionary or responsive in nature. Precautionary evacuation is desirable because it occurs before the population is at high risk. A responsive evacuation, in contrast, occurs after a release and could expose some or all evacuees to the hazard. Both types entail similar planning tasks: estimating the number of potential evacuees, with particular emphasis on special populations; identifying the most appropriate evacuation routes; designating needed traffic control;

estimating the time needed for evacuation; and anticipating potential problems.

Shelter-in-place is accomplished by shielding the public from exposure pathways for a hazard. This may include from vapors, aerosols and liquid contamination. Shelters may be congregate (for many people) or individualized (a home). Shelters may be existing structures, with or without upgraded protective measures, or facilities specifically designed to provide shelter from toxic chemicals.

In CSEPP there are four types of shelter-in-place: normal, expedient, enhanced, and pressurized. Normal shelter-in-place involves taking cover in a building, closing all doors and windows, and turning off ventilation systems. Effectiveness is improved by going into an interior room. The shelter should be opened up or abandoned after the toxic plume has passed.

Expedient shelter-in-place is similar to normal shelter-in-place except that, after going into the room selected as a shelter at the time of an emergency, the inhabitants take measures to reduce the rate at which air or chemical agent enters the room. Such measures would include taping around doors and windows and covering vents and electrical outlets with plastic. Effectiveness is improved if the room selected as a shelter is an interior room. The shelter should be opened up or abandoned after the plume has passed.

Enhanced shelter-in-place is similar to normal shelter-in-place except that it involves taking shelter in a structure to which weatherization techniques have been applied before the emergency to permanently reduce the rate at which air or chemical agent seeps into the structure. Effectiveness is improved by going into an interior room. The shelter should be opened up or abandoned after the toxic plume has passed.

Pressurized shelter-in-place is similar to normal shelter-in-place except that the infiltration of contaminated air from outside the shelter is effectively prohibited by drawing outside air into the shelter through a filter that removes chemical agent. This filtered air creates a positive pressure in the shelter so that clean air is leaking out instead of contaminated air leaking in.

Appendix D of the CSEPP Planning Guidance defines shelter policy for CSEPP (Oak Ridge National Laboratory and Schneider Engineers, 1994). According to Appendix D, the protective actions to be included in each protective action strategy should be selected according to the following criteria:

a. Evacuation should be recommended under all situations when it can be completed before arrival of the toxic plume.

b. Sheltering options are graphically depicted in Fig. 1. Normal shelter-in-place should be recommended for the general population and for special populations and institutions in the IRZ and PAZ under conditions that would not allow evacuation before the arrival of a potentially life threatening level of chemical agent.

   If normal shelter-in-place does not provide adequate protection for any category of accident, members of the general public, institutions, and special populations within the no death distance or within the IRZ boundary if the no death distance exceeds the IRZ are eligible for the Enhanced Shelter Program and/or for expedient sheltering of one room in a house.

   Members of the general public, institutions, and special populations who cannot evacuate before the arrival of a potentially life threatening level of chemical agent and who are beyond the no death distance but are in the IRZ or within the no death distance and in the PAZ are eligible for expedient sheltering of one room in a house.

   Members of the general public, institutions, and special populations who cannot evacuate before the arrival of a potentially life threatening level of chemical agent and are outside the no death distance in the PAZ are only eligible for normal shelter-in-place.

c. Pressurized/filtered shelter-in-place should be recommended for special populations and institutions within the no death distance who cannot evacuate before the arrival of a potentially life threatening level of chemical agent and for which the measures listed in item b would not provide adequate protection. Facilities/structures that are pressurized would not be eligible for transportation resources to aid an evacuation.

   Thus CSEPP does not embrace the concept of collective protection for the general population. The rationale is once people are evacuating it is better to have them leave the area at risk rather than to stop and seek shelter in a collocated facility.

PADRE

PADRE or the Protective Action Dose Reduction Estimator is designed to assist in assessing the conditions under which sheltering in place or evacuation is the preferred action (Sorensen et. al., 1992). To do so it present the user with dialog screens to set accident parameters, to specify the emergency response, and the protective actions employed. PADRE then graphically presents the user with the results of the analysis. The results are portrayed as the accumulation of the outside dosage of a chemical agent over time for someone taking no protective action and for the accumulated dosage given the chosen emergency system and protective action. Various parameters from the model results are displayed graphically and in text form as well. Planners can see when the plume arrives, when it departs,

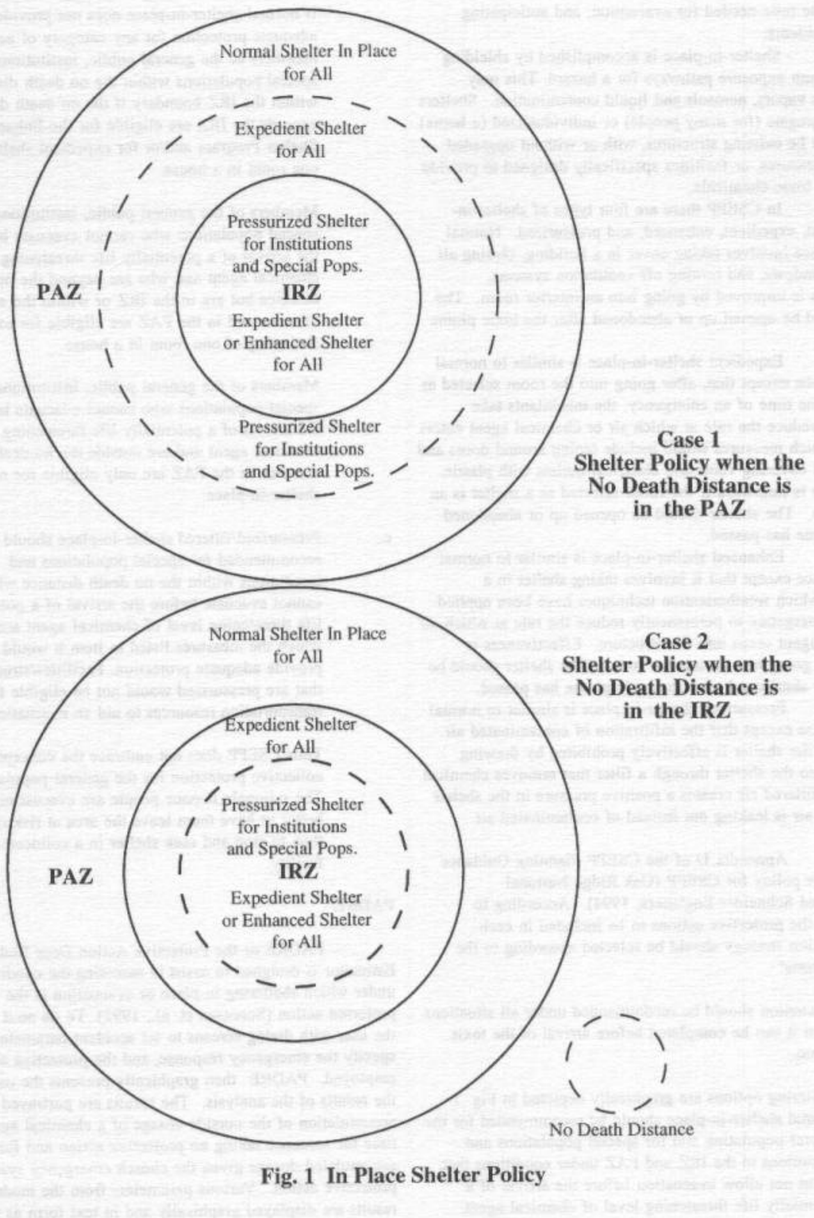

Fig. 1 In Place Shelter Policy

the expected dose reduction from the protective action scenario, and how much more dose savings can be achieved by reducing response time. PADRE allows the user to change scenarios (i.e., different size accidents, different met conditions, different public warning systems, different speed of public response, or different protective actions) and analyze the change in exposure to chemical agents.

The user generates an accident-release scenario, inputs meteorological conditions, and specifies an air exchange rate for a structure. In addition, PADRE takes into account how long officials take to issue a warning, the type of warning system in place to alert the public including sirens, tone alert radios and others, and the speed of public response. For evacuation PADRE calculates a clearance time based on the speed of the traffic and a safe distance. For sheltering, PADRE includes normal sheltering as well as taping and sealing a room. Trials were conducted to measure the reduction in air exchange rates for the tape and seal strategy. In addition, the user may elect to protect people engaged in certain activities such as being home asleep or at work.

Research Questions

In this paper PADRE is used to take a preliminary look at 5 research questions regarding the effectiveness of sheltering in place for chemical weapons accidents:

- Does the relative effectiveness of sheltering decline with the duration of the chemical release?
- Should shelters be vacated or ventilated to reduce dose?
- When is the optimum time to leave a shelter in relationship to plume passage?.
- Do people need timely decision warning and response in order to obtain benefits of shelter?
- Is a poorly implemented shelter strategy worse than standing outside in plume?

Research Results

- Does the relative effectiveness of sheltering decline with the duration of the chemical release?
- Should shelters be vacated or ventilated to reduce dose?
- When is the optimum time to leave a shelter in relationship to plume passage?.

Previous research has suggested it is important to ventilate a shelter after the plume has passed by a shelter (Rogers, et. al. 1990). This is primarily due to the fact that agent is trapped in the shelter when the plume passes by and remains after the plume has gone. People in the shelter are exposed to air contaminated by agent vapors, while the outside air is no longer contaminated.

Work with PADRE suggests a more complex relationship. To minimize dose, the optimum time to vacate a shelter will occur in most cases prior to the plume passage. This will occur at the point in which the concentration outside drops below the concentration inside. At this point the dose accumulates faster in the shelter than in the plume. Thus if a person evacuates near the tail end of the plume passage, they will be better off than if they act "conservatively" and wait until they are sure the plume has totally passed by.

- Do people need timely decision warning and response in order to obtain benefits of shelter?
- Is a poorly implemented shelter strategy worse than standing outside in plume?

Sheltering requires rapid decision making and a quick notification of the public at risk to be implemented prior to plume arrival. The precise speed of decision making and warning to support an effective sheltering strategy will vary with circumstance. What are the consequences, however, of being caught in the process of sheltering? PADRE is used to assess some of the ramifications of slow decision making in a fast moving scenario.

Table one shows the results of a scenario involving the release of chemical agent. The scenario used is a 400 LB puff release under D stability and 1 mps wind speed. The structures involved, located 2 km downwind from the release, have an air exchange rate of 1.5 ach. In the base case scenario we assume that officials make a quick decision (5 min.) to shelter and disseminate the warning using a sophisticated warning system. We also assume a rapid public response to implement the action. In the bases case 76% of those at risk have implemented the action when the plume arrives and the average exposure reduction is 76% of the outside population exposure. If the decision is delayed another 5 minutes the exposure reduction drops only slightly to 70%. However, taking 20 minutes, reduces the exposure reduction to 36%, and for 30 minutes to 3%. Thus delaying the decision has dramatic effects on the effectiveness of sheltering. This is assuming that people vacate the shelter at an optimum time. Table one shows in the base case that sheltering has little exposure reduction if people remain in the shelter. As decision time increases, sheltering has counterproductive effects. With a 30 minute delay in warning, the dose is estimated to be two thirds larger than if a person remained outside in the plume. In this scenario most houses have agent infiltrate before they are closed up, and then people trap the high concentrations in the shelters. As a point of comparison note that a 60 minute delay leads to lower potential for dose increase for a unventilated shelter as the plume passes by before the shelters are closed up.

If we look at the same situation only with a taped and sealed room (infiltration of 0.15 ach), the same pattern is found, albeit with higher protection. Still the benefits of the super tight shelter largely disappear with a 30 minute

Table 1. Effects of alternative decision delays on exposure reduction

	5 min.	10 min	20 min	30 min	60 min
Percent Implemented At Plume Arrival	76	54	3	0	0
1.5 ach					
exposure reduction (%) vacated	76	70	36	2	0
exposure reduction (%) not vacated	3	+8	+40	+67	+32
0.15 ach					
exposure reduction (%) vacated	87	81	44	3	0
exposure reduction (%) not vacated	59	54	17	+23	+20

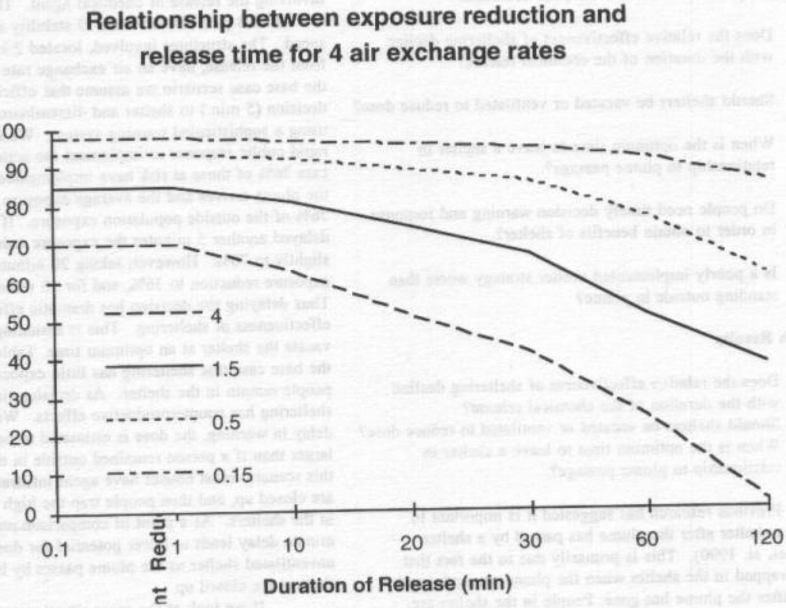

Fig. 2: Exposure Reduction for Different Release Times

delay in warning.

CONCLUSIONS

Shelter is less effective for releases of a longer duration. This is particularly true for structures with relatively high air exchange rates. As the air exchange rate decreases, shelters are viable protection for longer duration releases.

The optimum time to vacate a shelter will likely occur prior to the passage of the tail of the plume. Thus officials are better off to order an early vacating of a shelter than to wait until they are confident the entire plume has passed by.

Sheltering requires attention to the timing of decision making and the ability to warn the public. Delays in a timely decision may cancel out any benefits of shelter or, even worse lead to greater exposure that not sheltering at all.

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TIEMEC '95

Chemical Stockpile Emergency Preparedness Program Issues III: Planning Issues

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TECHNICAL BASIS FOR CHEMICAL STOCKPILE EMERGENCY PLANNING

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KEYWORDS

chemical stockpile, dispersion modeling, planning, protective actions

ABSTRACT

As part of the Chemical Stockpile Emergency Preparedness Program, an Accident Planning Base Review Group (APBRG) was convened in December 1992. The APBRG's mission was to update the accident basis for protective action strategy planning in the vicinity of eight U.S. chemical agent stockpile sites. The results of the APBRG's work are being issued as site-specific Emergency Planning Guides (EPGs). The EPGs give emergency planners—Army, State, and local—an updated assessment of the chemical hazard and guidance on how to plan for a broad range of accidents by planning for a manageable number of accident categories. This paper addresses:

- The rationale for updating the accident planning base.
- The modeling methodology used to assess the chemical hazard.
- Strategies that are advocated in the EPGs for the use of models by planners.

RATIONALE FOR UPDATING THE PLANNING BASE

In December 1992, the Planning Subcommittee of the Chemical Stockpile Emergency Preparedness Program (CSEPP) convened a new working group, the Accident Planning Base Review Group (APBRG). The APBRG's mission was to update the accident planning base for CSEPP. The need for such action was driven by a number of changes in CSEPP and in the Chemical Stockpile Disposal Program (CSDP) since the publication of site-specific Emergency Response Concept Plans (ERCPs) for each chemical stockpile site in 1989. These changes include the reassessment of dispersion distances; changes in CSDP process design and operations; and a movement to base planning on accident categories instead of on the original accident scenarios.

Historical Background

A risk assessment was conducted in 1987 on the subject of the proposed destruction of the U.S. inventory of lethal, unitary chemical agents and munitions (U.S. Department of the Army 1987). The assessment provided input to a *Final Programmatic Environmental Impact Statement* (FPEIS) (U.S. Department of the Army 1988). This risk analysis was based on the Johnston Atoll Chemical Agent Disposal System (JACADS) design (then at its 60% completion level), and modified by conceptual changes planned for implementation at the proposed continental U.S. facilities. Over 3,000 hypothetical accidents that could occur during storage, destruction, and disposal operations at eight Army depots were identified and analyzed.

Based on this risk assessment and other relevant information, the ERCP writers attempted to describe the distribution of accidental releases for the chemical stockpile and to develop planning basis accidents for the Army installations and their surrounding vicinities. Accident categories developed in the ERCPs were based principally on the variation in downwind lethal distance and duration of release found in the distribution of accidental releases for the Army installations. The accident categories were intended to represent ranges of values for variables that could affect the dispersion of chemical agent downwind and any subsequent human health effects for unprotected people. Accident categories identified in the ERCPs were typically structured like the examples in Table 1 (Carnes et al. 1989).

Table 1. Example Categories From Historical Planning Basis Accidents

Category 1	a small release with no off-site fatalities.
Category 2	a moderate short-term or instantaneous release with fatalities confined within approximately 10 km.
Category 3	a moderate long-term or continuous release with fatalities confined within approximately 10 km.
Category 4	a large short-term or instantaneous release with fatalities confined within approximately 25 km.
Category 5	a large long-term or continuous release with fatalities confined within approximately 25 km.

The accident categories identified as part of the APBRG activity differ from these historical categories. The historical categories were meant to be used with site topography, meteorology, and population distribution to identify emergency planning zones and appropriate protective actions for populations within those zones. But, the listing of accident scenarios in the ERCPs led many planners to focus on individual accident scenarios rather than categories as the basis for developing off–post emergency response plans. The idea of these planning basis accidents, however, was not that planning should take place only for these accidents, but that the accident distribution in the ERCPs could serve as a reasonable range of accidents for which to plan. It is quite possible that if there is ever an accident associated with the inventory at any of the CSDP installations, it will not be one of the accidents identified in the ERCPs. The accident should, however, resemble an ERCP accident in terms of cause, source term, and other critical variables. Thus, if planning and preparedness have taken place for the range of critical values represented by accidents in the ERCPs, then that planning and preparedness should also address whatever accident might actually happen.

Changes in Accident Distribution

Although the general approach to developing emergency planning zones and identifying protective actions recommended in the ERCPs is still sound, changes have occurred since their publication with respect to these issues, including the distribution of potential accidental releases for the chemical stockpiles, that recommend a reconsideration of accident categories. Moreover, given the potentially very short decision-making, alert and notification, and response times available for some accidental releases, it is important that the CSEPP planning community move from attempting to develop protective actions and protective action strategy plans for many individual accident scenarios to develop protective action strategy plans for a much smaller number of categories of potential accidental releases.

Since publication of the ERCPs, the CSDP has identified a number of design and procedural changes that result in a somewhat different distribution of potential accidental releases for the chemical inventory. Such design changes resulted from Army efforts to make the disposal operations safer, to make the plants more efficient in disassembling munitions and in destroying agents, to incorporate lessons learned from similar disposal operations at JACADS and other facilities, and to comply with environmental permit requirements that change over time and vary from state to state. In no case did these design changes result in the potential for downwind lethal distances greater than other dominant accidents at the Army installations.

Changes in Pertinent Data

1990 Census data are now available for all sites. In addition, some sites have more recent local estimates of demographic data. Hence, there existed a present and ongoing need to reassess the numbers of people potentially at risk and the locations of those people. Also, some locations have local, site-specific meteorological data available that is more characteristic of their vicinity than the sometimes distant National Weather Service data used in the ERCPs.

Current Status

Efforts are underway to consolidate the data and results of the analysis of risks associated with design and procedure changes in the CSDP (in support of the site-specific environmental impact statement for each proposed disposal facility) for use in CSEPP planning. When those efforts are completed, the entire and up-to-date distribution of accidental releases identified for storage and disposal of the chemical inventory will be compiled for CSEPP planning purposes.

Since the conclusions of those analyses are already available and indicate that these changes did not result in downwind no-death distances greater than other dominant accidents for the chemical inventory, work has been able to proceed with developing new accident categories for the CSEPP effort. Additional information about the new accidents (such as quantities of agent released, specific downwind no-effect distances, etc.) can be incorporated when it becomes available.

Because protective action planning in CSEPP should focus on factors other than pre-identified accident scenarios, the accident planning base has been revised to focus on these factors. The planning base still incorporates the full range of credible accident scenarios. But, the scenarios are now grouped into categories based on the important decision making factors. For example, two scenarios that might represent different physical occurrences, happening under different weather conditions, might result in the same distance, time, and level of exposure downwind. Thus, those scenarios could be grouped into the same category for planning purposes. The EPGs contain a complete description of such categories for each CSEPP site, on which planners should base any new planning efforts or revisions to existing plans.

MODELING METHODOLOGY

As in the risk analysis, FPEIS, and ERCPs, the present analysis uses the Army's approved dispersion model, D2PC. But, the current update features a more realistic and site-specific characterization of the accidents that are analyzed than before.

In the present analysis the method used to apply D2PC to the release scenarios sought to characterize each accident as realistically as possible. The downwind distances to the locations where the dosage level corresponds to no deaths and to no effects were calculated using the toxicity levels built into the D2PC model. Two sets of environmental conditions were considered – one for releases during neutrally stable atmospheric conditions (wind speed of 3 m/s, atmospheric stability class D), and one for releases during relatively stable atmospheric conditions (wind speed of 1 m/s, atmospheric stability class E). Environmental conditions corresponding to the summer season were chosen because the warmer temperatures and lower mixing layer heights associated with summer will tend to result in higher evaporation rates and lower atmospheric mixing leading to more conservative (larger) estimates of the potential extent of the downwind hazard.

The scenarios, as taken from the ERCPs, are identified by:

- the activity taking place when the accidental release occurs (handling during storage, long-term storage, handling for demilitarization, on-site transportation, handling at the demilitarization facility, or plant operations at the demilitarization facility);
- the type of munition involved (105 mm cartridges, 4.2-inch mortar shells, M23 land mines, 155-mm projectiles, 8-inch projectiles, M55 rockets, 750 lb bombs, spray tanks, or ton containers);
- the type of agent contained in the munitions (nerve agent GB, blister agent mustard, or nerve agent VX);
- the release mode (complex, fire, or spill); and,
- the specific release event (an arbitrary index number).

When the individual release scenarios were established, the quantity of agent released and the duration of the release event were estimated for each scenario. The quantity of agent released is expressed in terms of three components:

- the quantity spilled, which represents the amount of agent that is released in such a way as to form a puddle of liquid agent at the location of the munitions involved. This usually will be on a hard surface such as the concrete floor of the demilitarization or storage facility or on the roadways and aprons. Before the liquid agent is neutralized or otherwise cleaned up, some or all of it will enter the atmosphere through evaporation;

- the quantity detonated (Q_D), which represents the quantity of agent contained in the munitions that detonate during the release event thus essentially instantaneously releasing agent to the atmosphere as either vapor or aerosol. By dividing Q_D by the fill weights of individual munitions, the equivalent number of munitions detonated (N_D) during the release event can be calculated; and,
- the quantity emitted, representing agent that is "violently" released from munitions that do not detonate during the event but that rupture due to the detonation of other munitions or due to an accompanying fire. This agent is released directly to the atmosphere but over a finite period of time. Within the D2PC model, this type of release is referred to as a semi-continuous release.

If the release event occurs inside a closed building or structure that remains relatively intact, the effective release to the outside atmosphere is moderated by the presence of the building. For example, evaporation will be slowed because the air in the building is relatively still compared to the external atmospheric winds. In addition, instantaneous explosive releases due to munition detonation will effectively be spread out over time due to the confining effect of the building. Agents like VX and mustard, that are not particularly volatile, will be deposited on the interior surfaces of the building in the form of liquid droplets as result of the detonation. That deposited liquid will then evaporate over time, until it is neutralized or otherwise cleaned up, and be released to the outside atmosphere as the air within the building or structure is relatively slowly exchanged with outside air. As a consequence, when applying the D2PC model to a specific release scenario, a different approach must be used for releases that occur inside closed buildings or structures compared with releases that occur outside. Whenever a particular release event could occur either outside or inside or when the release event most likely would destroy the containment effectiveness of the building or structure, an outside release was assumed. This is considered to be a conservative assumption because no credit is taken for the potential mitigating effects of initial confinement.

The D2PC model contains a database of site-specific, munition-specific, and agent-specific parameter values. To the extent possible, these "default" values were used in the present analyses.

Six basic approaches were used depending on the agent involved and whether the release is considered to be outside or inside a closed structure. A description of these approaches follows. The vapor depletion option of D2PC, which accounts for the removal of a portion of the transported vapor from the atmosphere due to contact with the ground surface, trees, etc., was not used in the present analyses. This option only applies to the vapor portion of a release. Neglecting vapor depletion does not have a major effect on the model predictions; what effect it does have will tend to be conservative because all the vapor released will remain in the transported cloud and contribute to the dosage at downwind locations.

Release Outside

The contributions to the downwind dosage resulting from the detonation of N_D munitions, the semi-continuous release of emitted agent, and the evaporation of spilled agent were calculated and then added using the built-in dosage summing capability of D2PC. The contribution from the detonation of N_D munitions was calculated using a release type of "instantaneous." The contribution from the semi-continuous release of the emitted agent was calculated using a munition type of "non-munition" and a release type of "semi-continuous." The contribution from the evaporative release of spilled agent was calculated using a munition type of "non-munition" and a release type of "evaporative." A minimum evaporation time of 60 minutes was assumed because it represents the typical time it takes to respond to a spill and neutralize it or clean it up. The time may be longer for particular scenarios.

Release Inside

The downwind hazard distances resulting from a release inside a closed building or structure were estimated by first calculating the amount of agent that could become airborne and escape the building from the various sources (detonated, emitted, and spilled). Then the contributions to the downwind dosage resulting from the semi-continuous release of each of the sources were calculated and added using the built-in dosage summing capability of D2PC.

For GB releases, the quantity of agent to be released from the closed building resulting from the detonation of N_D munitions inside the building was calculated using a release type of "instantaneous." Not all the agent in the munitions is available for release because a portion of the GB is destroyed during the detonation. Because of the high volatility of GB, it was assumed that the agent that would be available for release would be primarily in vapor form. The quantity available for release was a result calculated by D2PC.

For mustard and VX releases, the quantity of agent to be released from the closed building resulting from the detonation of N_D munitions inside the building was estimated by assuming that the detonation of the munitions results in all the liquid agent contained in those munitions being "splattered" all over the interior of the building. The liquid agent was then assumed to evaporate over time to contribute to the quantity available for release. The contribution to the quantity available for release was calculated using a release type of "evaporation in still air" and a minimum evaporation time of 60 minutes. The area of wetted surface was assumed to be 2.4×10^4 m^2. This is an arbitrary value but represents the interior surface area (walls, floor, and ceiling) of a 100 m x 100 m x 10 m building. This parameter was assigned a particularly large value so as to promote evaporation and lead to a large and thus conservative quantity available for release. The length of surface downwind was assumed to be 10 m. This, too, is an arbitrary value but is probably typical of the shortest dimension of the room or area where the detonation might take place. This parameter was assigned a particularly small value so as to promote evaporation and lead to a large and thus conservative quantity available for release. The resulting quantity available for release through subsequent evaporation and the actual time of evaporation, which may be less than the input time, were calculated by D2PC.

The quantity of agent to be released from the closed building resulting from the evaporation of the spilled agent was calculated using a munition type of "non-munition" and a release type of "evaporation in still air." A concrete surface and a minimum evaporation time of 60 minutes were assumed.

The quantity of agent available through evaporation and the actual time of evaporation were calculated by D2PC.

Next, the contributions from the various sources (detonated, emitted, and spilled) to the downwind dosage were calculated using a release type of "semi-continuous." The results of the previous calculations were used as inputs to this calculation. An effective release time of at least 20 minutes was assumed because it is representative of the air turnover time in a storage igloo (approximately three air exchanges per hour).

USE OF EPG AND D2PC BY PLANNERS

In updating the CSEPP planning base, the APBRG sought:

- to inform the site planning community (State, local, and installation CSEPP planners) of changes to the planning base as information unfolded throughout the process;
- to involve the site planning community in documentation of the planning base, so as to create shared ownership of the final products; and
- to address and promote site-specific development of protective action strategy plans.

The APBRG wished to publish the revised planning base in a form that would be of practical use to State, local, and installation CSEPP planners. For this reason, the group concluded that it would be appropriate to publish eight site-specific Emergency Planning Guides (EPGs) that explain how to use the information they contain to develop protective action strategy plans.

The EPGs are intended for the use of Army installation and off-post planners. The EPGs give planners procedures they can follow to develop protective action strategy plans and implementing procedures. They are meant to be of use in developing, revising, and updating plans to protect the public in case of a chemical stockpile emergency at a stockpile location.

The EPGs supersede the ERCPs. The EPGs present site-specific data that are pertinent for planning, and give practical instruction in how to develop protective action strategy plans.

Each EPG has four major parts:

- Part I contains data that characterize the Army installation and the surrounding vicinity. These data include geographic characteristics, demographic characteristics, and socioeconomic/infrastructure characteristics.
- Part II characterizes the chemical stockpile hazard at the Army installation. This part includes a description of the hazard, a discussion of risk analysis, a discussion of the use of the D2PC model to estimate the consequences of accidental releases, and an identification of accident categories as a basis for protective action planning.
- Part III discusses protective action strategies for CSEPP, protective action decision making, the use of computer models in protective action planning, and the process of developing protective action strategy plans.
- Appendices present technical data and additional discussion supporting the derivation of accident categories. The appendices include a discussion of the rationale for reexamining the CSEPP planning base, tables of distance calculations, a description of how the distances were derived, Material Safety Data Sheets for the chemical agents, and a glossary of terms and acronyms.

The EPGs focus on the use of accident categories rather than scenarios as the basis for developing protective action strategy plans. In the EPGs, the scenarios that were cited in the previous ERCPs have been sorted into a small number of categories based on the distance to which the hazardous effects of each scenario might extend. Planners are guided to develop plans for this small number of categories rather than for a large number of scenarios for two practical reasons:

- At the time of an accident, the information immediately available from the installation is likely to be rather limited. Indeed, at first report, it may be unknown what caused a release of chemical agent. For reaching a protective action decision, it may not matter what caused the release of agent (that is, what scenario is in effect). What matters is: how far are hazardous effects likely to extend, in what direction, how soon, and for how long? The accident categories are designed to provide that level of immediately available, basically required information to planners and decision makers.
- Because of the speed with which protective action decisions must be reached for a chemical agent release, decision makers will not have enough time at the time of an accident to sort through a large number of possible protective action strategies. To enable a decision to be made quickly, the number of options must be kept small. The accident categories are designed to support the grouping of what could be a large number of options into just a few.

Different sites have consolidated their accidents differently, in keeping with local circumstances and planning philosophies. For example, some sites have a diverse inventory of chemical munitions, encompassing many different combinations of agent type and munition type. Other sites have a less diverse inventory—for example, only one agent type and one type of munition or storage container. For the former sites, in order to simplify protective action planning, it is preferable for accident categories to cut across various agent/munition combinations. A category might be defined, for example, to encompass any chemical incident necessitating public protective action (evacuation or in-place sheltering) out to a certain distance. Using such a categorization scheme, it would not matter (for the sake of public protective action planning) whether the hazard were caused by the release of a certain quantity of nerve agent GB, or of a different quantity of mustard. The consequences would be the same for protective action decision making.

For the less diverse storage sites, a different categorization philosophy may be appropriate. For example, one site stores only ton containers of nerve agent VX. For such a site, categories may be more logically related to the number of munitions or containers involved in a release, rather than to the resulting hazard distance. Though the resulting hazard distance is still important for public protective action planning, it might not be the organizing principle for categorizing accidents at such a site.

The EPGs contain extensive discussions of how to use the D2PC atmospheric dispersion model, and of cautions that the user should be aware of in using D2PC. Emergency managers are cautioned, should a real incident happen, that their first reaction upon receiving a notification of a chemical agent accident should not be to run D2PC nor to wait for someone else to run it. Doing so will only lose valuable time that emergency managers and responders need for implementing a protective action. The accident categories in the EPG are designed to help emergency managers make appropriate protective action decisions without waiting to run D2PC first at the time of an accident.

Given those cautions, however, it is also important to note what are appropriate uses of D2PC:

- At the time of an accident, emergency managers are encouraged to run D2PC as time and available data allow, to perform ongoing assessment of the accident. They should not, however, put off implementing a protective action while waiting for a D2PC run.

- In the planning stage, planners are encouraged to run D2PC extensively to try out various options. Instructions are given in the EPGs to enable planners to reproduce the distances published in the EPGs. Planners are also encouraged to calculate other scenarios—vary the quantity of agent release, for instance, to find out "what happens if..." Even if they never touch D2PC during an actual incident, the insight they gain from running D2PC during the planning stage will give them a much better understanding of what is happening during an actual incident.

The D2PC model has been field tested extensively by the Army. Where conditions exist that approximate the assumptions of the model (such as flat terrain and steady weather conditions), D2PC estimates were found to be extremely accurate in comparison to the results of actual tests. However, in many cases D2PC will overestimate the hazard distance for a given quantity of release. This is because in the real world, many things impede the downwind movement of materials released to the atmosphere. For example, wind meandering and rough terrain (natural features or buildings) will interrupt the steady movement of a plume of agent. So, D2PC's estimate of downwind effects will usually be greater than that which would occur if an actual release took place. Therefore, the use of D2PC should enable planners to assure decision makers that the EPG accident categories, which are based on D2PC results, provide a conservative basis for protecting the public.

One problem with the results of the D2PC calculations published in the ERCPs was an inability on the part of planners or subsequent researchers to duplicate the results. Reasons for this inability included:

- *Incomplete publication of input data.* The ERCPs included the basic scenario data needed to reconstruct each model run. However, the D2PC model requires as inputs several quantities or assumptions that were not explicitly published. In the absence of published information, planners and technical consultants made choices of default inputs and assumptions that were reasonable, but differed from those used in the original analysis. Not surprisingly, therefore, their results differed from the earlier results.

- *Interpolation of some scenarios.* In the original analysis, some scenarios were not individually calculated by running the D2PC model. Rather, their results were estimated by interpolation between two scenarios that were individually calculated. Therefore, when later analysts tried to calculate all of the scenarios individually, even when they used correct inputs, they got different results from the previous interpolations.

- *Site-specific differences.* The original analysis was done generically for all sites. It did not account for site-specific differences such as in seasonal average temperatures or atmospheric mixing layer heights. Planners who later attempted to apply default assumptions for their own sites ended up with differences from the original analysis.

The APBRG aimed to counteract these problems in the present analysis. The APBRG's strategy was, first, to recalculate each of the scenarios for each of the sites, using site-specific data where appropriate. Secondly, the APBRG provided users of the EPGs with all of the information needed to reproduce the D2PC results. Using the provided data, planners are enabled to run the D2PC model themselves, and to derive the same results as published in the EPGs. Using the published analyses as templates, planners can also vary the inputs, with confidence that they are following the same calculation methodology as used in the EPGs.

To aid and encourage such use of the model, the inputs that were used to derive the EPG results have been included pictorially in the EPGs, in the form of Windows (TM) input screens. A typical input screen for one scenario at the Anniston Army Depot is shown in Figure 1. Using such a screen as a visual reference, planners can easily ensure that their inputs to D2PC match those used in the EPGs.

The ability to duplicate the D2PC results in the EPGs and to apply the same methodology to other scenarios gives planners several important advantages:

- Planners are able to verify the EPG results for themselves. They no longer have to blindly accept the numbers given to them by an outside source. They may, therefore, have more confidence in the model results as a valid basis for planning.

- Planners are able to reassure the public of the validity of the analysis. State and local planners should be able to enhance the credibility of CSEPP planning with the public by performing their own review and approval of the analysis performed by the APBRG.

- Planners are able to educate themselves by analyzing other "what if" scenarios. Such additional analyses can help them anticipate what sort of effects to expect should a chemical incident actually happen, even if the actual incident is not exactly like one of the scenarios they have analyzed.

CONCLUSIONS

The updating of the planning base for CSEPP has accomplished several worthwhile goals. From a technical standpoint, it has taken advantage of changes in the CSDP and better knowledge gained about the potential for chemical accidents since the publication of the ERCPs. It has also given planners an opportunity to incorporate more recent and site-specific data into their planning base. Strategically, the update has enabled planners to make better use of the planning base, first by focusing their attention on accident categories instead of individual accident scenarios, and second by providing them with the means to verify the analysis and conduct further analyses on their own.

ACKNOWLEDGMENT

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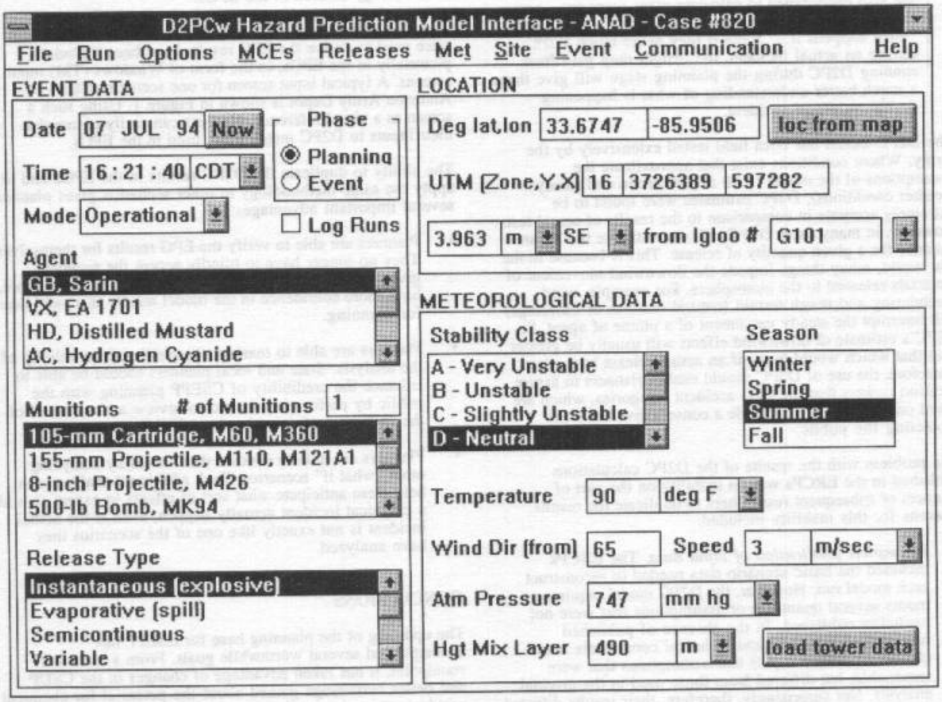
BIOGRAPHIES

Donald E. Newsom and Marc A. Madore are in the Emergency Systems Group at Argonne National Laboratory. Dr. Newsom led the technical effort at Argonne to update the CSEPP planning base. Mr. Madore is Deputy Program Manager at Argonne for the CSEPP Program. Robert A. Paddock and Mariska J. G. Absil are in the Systems Science Group. Dr. Paddock performed the dispersion modeling calculations for this project. Ms. Absil assisted with the calculations and developed the screen captures for publication.



EVENT DATA

Date 07 JUL 94

Time 16 : 21 : 40 CDT

Phase
● Planning
○ Event

Mode Operational

☐ Log Runs

Agent
GB, Sarin
VX, EA 1701
HD, Distilled Mustard
AC, Hydrogen Cyanide

Munitions # of Munitions 1
105-mm Cartridge, M60, M360
155-mm Projectile, M110, M121A1
8-inch Projectile, M426
500-lb Bomb, MK94

Release Type
Instantaneous (explosive)
Evaporative (spill)
Semicontinuous
Variable

LOCATION

Deg lat,lon 33.6747 -85.9506

UTM (Zone,Y,X) 16 3726389 597282

3.963 m SE from Igloo # G101

METEOROLOGICAL DATA

Stability Class
A - Very Unstable
B - Unstable
C - Slightly Unstable
D - Neutral

Season
Winter
Spring
Summer
Fall

Temperature 90 deg F

Wind Dir (from) 65 Speed 3 m/sec

Atm Pressure 747 mm hg

Hgt Mix Layer 490 m

Figure 1. Sample Input Screen for the D2PC Model

RISK COMMUNICATIONS AND THE CHEMICAL STOCKPILE EMERGENCY PREPAREDNESS PROGRAM

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KEYWORDS

chemical agents, risk, communication.

ABSTRACT

Risk communication has long been undertaken by various entities - individuals, scientists, technicians, agencies, governments, industry, interest groups, and the media - for various intents and purposes. The acceptance of risk communication as a distinct concept is a positive step for those involved in risk management because it helps to call attention to a the vital aspect of providing a common language (Leiss and Krewski 1987) with which issues and perspectives, as well as basic assumptions, can be examined and discussed. The rapidly expanding body of literature on risk communication is proof of that acceptance.

One of the greater challenges the Army faces is effectively dealing with the concerns of the public, local officials and the news media on the disposal of aging chemical agents. This paper describes the method developed for the Chemical Stockpile Emergency Preparedness Program (CSEPP) The purpose was to provide a fairly comprehensive document on risk communication research and recommended practices as they related to the CSEPP. Using the communications perspective suggested by Covello and colleagues, the existing practices of communicating risk information about chemical weapons and the associated efforts in emergency planning, storage and eventual disposal are described. Risk communication problems specific to the CSEPP are then examined and described via scenarios.

A framework is developed that distinguishes between the major components of risk communication, flow and intent. Within this framework, the research and recommendations are summarized as to direction of flow - dialogue, or two- way interaction, versus monologue, or one-way communication - and that of intent - exchange versus persuasion. The findings and recommendations are synthesized and related to risk events for the CSEPP as posited in the scenarios.

The findings indicate that the media will continue to heavily influence risk information provided by public or private sources, and in some instances act as a source themselves. Risk communicators for the CSEPP will face increasing pressure to present risk issues in a fair and unbiased manner as well as answer questions raised by various parties and constituencies. While there is no guarantee, there is every indication that a better understanding of risks of chemical agents by individuals and communities can be developed and preparedness strategies enhanced for the CSEPP through more effective risk communication programs.

INTRODUCTION

Risk communication has long been undertaken by various entities - individuals, scientists, technicians, agencies, governments, industry, interest groups, and the media - for various intents and purposes. The acceptance of risk communication as a distinct concept is a positive step for those involved in risk management because it helps direct attention to the vital aspect of providing a common language (Leiss and Krewski 1987) with which issues and perspectives about risk, as well as basic assumptions about risk assessment, can be examined and discussed. The rapidly expanding body of literature on risk communication is proof of that acceptance.

This paper describes the process of developing a document on risk communication for the Chemical Stockpile Emergency Preparedness Program (CSEPP). The purpose was to provide a fairly comprehensive document on risk communication research and recommended practices as they related to the CSEPP for emergency managers, CSEPP personnel, and local officials. Using the communications perspective suggested by Covello and colleagues, the existing practices of communicating risk information about chemical weapons and the associated efforts in emergency planning, continued storage, and eventual disposal are described. Scenarios specific to the CSEPP provide a platform for assessing risk communication problems.

Description of Communication Problem

One challenge both the Army and Federal

Emergency Management Agency (FEMA) face is effectively addressing the concerns of the public, local officials, and media representatives on the risks from continued storage and eventual disposal of aging chemical agent munitions via incineration at each site. Although the arsenal of weapons was never deployed, the deteriorating condition of the munitions (some in existence since the early 1940's) prompted Congress in 1985 to order the Department of Defense to destroy the existing stockpile. As required by National Environmental Policy Act (NEPA) for federal actions, the Army initiated and then issued a programmatic environmental impact statement (PEIS) identifying the risks for on-going storage and for disposal and discussing mitigation measures. As with all NEPA documents, comments were solicited from various publics and agencies on the proposed action.

One mitigation measure for both the continued storage and the proposed action was the upgrading of local emergency preparedness and response programs. Consequently, the Army developed a unique umbrella program called the Chemical Stockpile Emergency Preparedness Program (CSEPP) to facilitate the upgrading process. Although the Army has overall responsibility of emergency preparedness (and emergency planning) programs on military installations, the FEMA administers the civilian emergency preparedness programs in the states and local communities where the installations were located. Coordination between the Army, FEMA, and state and local officials is considered essential to the program.

Along with the oversight for emergency preparedness on military sites, the Army has the responsibility to alert the communities in the event of an accidental release of chemical agent. Since the populations surrounding the installations were largely unaware of the potential risks of chemical agents (along with general public knowledge until the Gulf war and the media coverage of Desert Storm), determining how to communicate to the various publics the risks from storage and the potential risk from a release of chemical agent off-post placed the Army (and FEMA) in an awkward position. Since the Army had never publicly acknowledged the risk from the stored munitions at the eight sites prior to the PEIS, there was every indication that the populations potentially affected would be critical of any proposed action.

The Army's experience communicating risks has not always been forthright. Segments of the public - whether individuals, corporations, states, or media representatives - have voiced distrust of much of the information provided by Army spokespersons. The Dugway, Utah, inadvertent sheep kill from a chemical agent release in 1962 is still recalled as an example of military cover-up. Military personnel never conceded blame and reached a settlement out of court with the sheep farmers. In another incident involving a community next to a chemical munitions storage site, emergency personnel had to wait a week to hear from the commander of the installation that what appeared to be a massive fire on post was in reality the detonation of smokebombs that was done in a careless fashion. During that week, the installation denied having anything to do with the event that closed down an interstate highway and sent people to the hospital.

In other instances, however, Army installation commanders have tried to help the community understand the risks from chemical agents by initiating open-houses, inviting the public on post, and being as open as possible about the threat as well as the safety measures used to avoid accidents.

In all fairness to the Army, much of the information on the U.S. chemical weapon arsenal the Army can present to the public is "classified" and not available to the public for reasons of national security. Moreover, each of the eight sites is unique in the quantities and types of munitions stored and each installation has a separate history with the community. Thus the Army is restricted by internal regulations and a lack of control on what information can be released to the public. Furthermore, the Army can only recommend - not dictate- to communities what to do in the event of a potential release off post.

Risks from Chemical Munitions

A considerable amount of research has been done regarding people's limitations in assimilating and understanding information about health and environmental risks (Kasperson and Kasperson 1983; Covello 1983, 1989; Green 1984; Fischoff, 1985; Slovic 1987). Public perceptions are influenced by the memorability of past events or by imagining future events (Lichtenstein et al. 1978; Covello 1989). Triggers that make a hazard memorable may include intensive media coverage, particularly those that include video coverage (Wilkins 1987), or a vivid or dramatic film (Covello 1989). Likewise, risks that are not obvious, remain unsensationalized, are not tangible, or do not affect people immediately tend to be underestimated.

Understanding probabilistic information about risks is often difficult for people. When a risk is unfamiliar or when probabilities are very low but with a high consequence, people will use a variety of heuristic devices to try to understand the threat. The risks from the chemical agents fall into the low probability, high consequence category. The exacerbating factor is the extremely short timespan for taking protective action in the event of a chemical agent release. The projected estimates (depending on the amount of release and the meteorological conditions) indicates that only 6 to 8 minutes would elapse before the toxic plume would reach persons outside the military reservation. Given the normal delays in responding to a warning - understanding, believing, and personalizing (Sorensen and Mileti 1987), the time element involved in a potential release suggests a well designed risk communication program before the event occurs is critical to prompt implementation of protective action.

Methodology

Our strategy was to first describe the overall organization of the CSEPP, providing a historical background and discussing some of the initiating concerns for the CSEPP. We did this for two reasons: clarification of the risk issues and unfamiliarity with the general constructs of the program itself. We were unsure how many program participants were familiar with the initial assumptions in assessing the risks from the continued storage as well as the disposal options. One problem is that the CSEPP experiences constant change-over of civilian personnel. Many of the personnel involved originally with CSEPP are no longer with the program or even in the same agency. The problem is endemic throughout the local, state, and federal agencies involved in the CSEPP. This means that much of the program's development is unknown to those currently employed in the CSEPP- along with how the risk estimations and hazard analyses were derived. In addition, a number of volunteers are used in some sites and their training in risk - and risk communication - is generally even less than paid personnel.

To place the risks from continued storage of weapons in perspective, we developed a number of scenarios that posited circumstances emergency managers or local officials might encounter if an accidental release of chemical agent should occur in their community. The scenarios ranged from a minor on-post accident with no off-post release to the remote event of terrorist activity involving all levels of agencies in response activities. Each scenario was described and questions posed that reflected the issues that were likely to be raised. For example, one on-post accident scenario raised the issue of credibility of spokespersons in relating information to the media. No "canned" answers were provided. Instead, we stressed the process of developing a risk communication program and of maintaining dialogue between various factions of the public and agencies. An example problem set dealing with a problem of hazard identification is shown in Figure 1.

Other question sets were developed to exercise people to deal with communications when confronted with the following situations:

- public speculation about technical expertise,
- credibility of source/message,
- media as sources and channels,
- institutional credibility,
- accuracy/bias of message transmission,
- fear of citizen overreaction, and
- warning message dissemination.

Overall, 68 questions were developed to assist risk communicators in preparing to deal with various situations that may arise. However, the intent was not just to get people to think about responses to questions, but to facilitate CSEPP personnel in anticipating situations and the issues likely to arise if an accident occurred.

We then introduced a conceptual framework that described in general how a hazard is assessed and the risk from the hazard determined. We used basic social concepts taken from Kates (1978) *Risk Assessment of Environmental Hazard* to describe how risks are identified and assessed. The various methodologies and differences among assessment methods were also discussed. We then distinguished between risk assessment, risk analysis, risk management, and risk communication. When possible, we phrased the concepts to reflect CSEPP issues. For example, one of the questions involved the different interpretations among agencies for the same level of risk. We included a section on why experts and agencies might disagree, even when each provides a valid scientific answer. The discussion then focused on the different measurement techniques and the assumptions pertinent to an agency's directive.

A comprehensive search of the risk communication literature had suggested certain themes. Since our intent was to provide an overview on risk communication research and recommended practices as they related to the CSEPP, a thematic compendium on risk was developed. Using the communications perspective suggested by Covello and colleagues, the existing practices of communicating risk information about chemical weapons and the associated efforts in emergency planning, storage and eventual disposal were then disaggregated and described.

We introduced a conceptual framework that distinguished between two major components of risk communication, flow and intent. Within this framework, the research and recommendations were summarized as to direction of flow - dialogue, or two- way interaction, versus monologue, or one-way communication - and that of intent - exchange versus persuasion. Figure 2 illustrates the conceptual framework . The findings and recommendations were then synthesized and related to risk events for the CSEPP as posited in the initial scenarios.

We further defined flow and intent in risk communications by first describing the issues related to the direction of flow of information. Included were research results related to:

- the media's influence and/or coverage of events,
- the media's "gatekeeping" agenda,
- media from the marketing perspective, and
- ethical issues related to media representations of risk.

Because efforts at public education have been controversial, we included research findings on education of publics about risks to induce actions. Another section dealt with enhancing public participation, since some CSEPP managers had complained of apathy about risk issues in their communities.

Under issues of intent we discussed recommendations from the research related to:

- control of information,
- public warning needs,
- issues related to safety,
- credibility and/or erosion of public trust, and
- ethics and responsibilities of communicators to audiences.

Question Set 1 (Hazard Identification)

A storage tank of agent (HD-mustard) is found leaking into the soil by agency personnel conducting a routine inspection. The damage appears related to the initial deterioration of a valve on the canister containing the agent and, thus, unlikely to have leaked for a long period of time. After discovery, the release was reported to the Environmental Protection Agency (EPA).

QUESTION SET 1

- What is in the tank/canister?
- Can the chemical explode?
- Is the groundwater affected?
- Can the chemical be safely cleaned-up?
- How long will the cleanup take?
- How can we tell if people living near the site have been exposed to any chemicals?
- Are there any long-term health effects possible from the leak?
- Why are people being evacuated so long after the spill was discovered?
- Why can't I return to my home?
- How can I tell if it's safe to let my animals out after I get home?

Figure 1: Sample Scenario and Question Set

FLOW

INTENT	One-way	Two-way
Persuasion	**ONE-WAY PERSUASION** Experts are correct Public is uninformed or misinformed Style determines success Economic model of rationality Limited time frame Selected information	**TWO-WAY PERSUASION** Assumes non-rationality Dialogue is top-down Style will determine success Expert is correct Public is uninformed Limited timeframe
Exchange	**ONE-WAY EXCHANGE** Public will act on information Assumes "economic model of rationality" Often bureaucratic in nature Technical focus Limited and/or selected information	**TWO-WAY EXCHANGE** Assumes no absolute truths Assumes social process will determine success Assumes non-rationality Extended time frame Broad-encompassing Assumes multiple perspectives

Figure 2: Conceptual Model of Risk Communication Styles

When discussing channels, we emphasized using multiple channels to notify the public about risks and that notification of risk is a process not easily accomplished through one channel at one time. We further discussed using new technologies for channeling information (such as the now infamous internet connections) as well as using alternative channels to target information. For example, in neighborhoods with large ethnic or minority populations, targeting groups through local print media may be more successful than announcements in general newspapers.

Our major emphasis was on methods to enhance the communication process.

Focusing on preparing for risk communication, we discussed rumor control, evaluation of communication efforts, working with the media prior to an emergency, insuring coordination between agencies, and designing risk communication programs. We also touched on comprehending public behavior - why some programs never work despite the best planning, communicating uncertainty when no one knows the answers, maintaining audience appeal, and , finally, issuing warning messages.

The major points made regarding sources in risk communication related to credibility, enhancing credibility, and using multiple sources of information.

We discussed message content and style - communicator techniques, warning message techniques, and techniques to use when information is highly technical or difficult for general audiences to understand.

Finally, we synthesized the findings and conclusions for the CSEPP by returning to the scenarios first posited with further discussion. When the question sets are examined the crucial differences in how the issues are framed by the public, media and the agencies become evident. In the first situation the risk was defined as an agency problem by all parties whereas in the second and third, the incidents were defined by public or media sources as agency problems. Agency actions did not reflect that assessment. The fourth question was defined by the media not as a criminal event but as a newsmaking situation with the potential risk secondary to the media's interest in the event as a sensational "newspeg." The agencies involved, however, defined the crisis as much more serious with the media perceived as interfering. The fifth question reflected the issues of community right-to-know versus need-to-know as well as control of information that included changing institutional structures. The sixth and seventh questions related to the need for planning for anticipated media needs. The seventh question posited some of the questions that officials should be prepared to answer even in routine preparations. The last question set indicated what may happen should a release occur during storage or incineration, and addressed the need for timely, accurate notification and how those warnings needed to be disseminated to ensure maximum protection for the public at risk.

A general theme throughout the situations is that risk assessment and management are part of the problem in the risk communication process. The assumption that management is part of the communication process compounds the uncertainty about definition of the level of risk, who should be informed, and when that information should be given to the public. The communication problem for the CSEPP is a complicated process involving risk generators, risk bearers and associated interested parties, media representatives, and concerned citizen groups. A basic understanding of how the risk assessment for the chemical stockpile was conducted is critical to effective risk communication for the CSEPP.

CONCLUSION

Communicating information on the risks associated with both chemical agent storage and disposal will continue to occupy a significant part of the CSEPP. In addition, the media will continue to heavily influence risk information provided by public or private sources, and in some instances act as a source themselves.

As CSEPP is implemented, risk communicators are likely to face increasing pressure to present risk issues and respond to risk related questions raised by various parties and constituencies. Whether acting alone or with others, managers of public and private agencies, industry representatives and governmental bodies must accept that media communications outlets will significantly influence the agenda of most risk communication efforts. Furthermore, newer forms of communications will continue to alter methods used to translate assessments of risks for risk management. Immediate access to data via personal computers places managers in the position of making immediate decisions about conveying information about risks.

It is likely that some incidents have occurred at the stockpile sites that have led to some erosion in public confidence in those parties and agencies participating in emergency management. To regain and/or enhance credibility and trust will require changes and modifications that can only be instituted through structural or institutional chang - a process which appears undeniable, but not impossible in the CSEPP. While there is no guarantee, there is every indication that a better understanding of the potential risks of chemical agents by individuals and communities can be developed and preparedness strategies enhanced for the CSEPP through effective risk communication programs.

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TECHNICAL SUPPORT FOR RECOVERY PHASE DECISION-MAKING IN THE EVENT OF A CHEMICAL WARFARE AGENT RELEASE

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KEYWORDS: recovery phase, chemical warfare, nerve agents, vesicants, monitoring

ABSTRACT

Persistent chemical warfare agents such as the nerve agent VX and sulfur mustard were originally designed as "terrain denial" materials on the chemical battlefield. As a consequence, they do not rapidly degrade. In the course of preparedness planning for disposal of the U.S. unitary stockpile of chemical warfare agents, communities have raised the issue of determining environmental concentrations and the potential health consequences of persistent agents following any agent event. This issue is common to several chemical warfare munition and materiel disposal activities in the United States, as well as for developing verification and compliance monitoring programs integral to the international Chemical Weapons Convention.

Experimental research supporting the development of environmental monitoring protocols are summarized. They include the development of blood cholinesterase activity as a biomonitor of nerve agent exposure in domestic beef and dairy cattle, horses and sheep; measuring the permeation rates of construction materials such as unpainted wood and gypsum wall board to agent simulants; and developing an experimental monitoring protocol for agents in meat and grain.

INTRODUCTION

In late 1985, Congress mandated that the U.S. stockpile of lethal unitary chemical agents and munitions be destroyed by the Department of the Army in a manner that provides maximum protection to the environment, the general public and personnel involved in the disposal program (Public Law 99-1, Section 1412, Title 14, Part b). These unitary munitions were last manufactured in the late 1960's. The stockpiled inventory is estimated to approximate 25,000-30,000 tons (Anft, 1988), and includes organophosphate ("nerve") agents such as VX [O-ethyl ester of S-(diisopropyl aminoethyl) methyl phosphonothiolate, $C_{11}H_{26}NO_2PS$] and vesicant ("blister") agents such as HD [sulfur mustard; bis (2-chloroethyl sulfide), $C_4H_8Cl_2S$]. The method of agent destruction selected by the Department of the Army is combined high-temperature and high-residence time incineration at secured military installations where munitions are currently stockpiled (eight facilities in the continental United States and one on Johnston Atoll in the South Pacific; Carnes 1989). Several of these installations are located in agricultural areas where production of livestock, pasture and row crops is important to local economies. In the unlikely event of an agent release being atmospherically transported outside the installation boundaries during continued storage or any stage of agent destruction, food, forage crops and structures will likely be suspected of surface contamination. Meat or milk could also become suspect from livestock ingestion of, or contact with, potentially contaminated forage or other materials. This issue is especially problematic for the persistent agents VX and HD, which were originally designed as "terrain denial" materials on the chemical battlefield. Due to their persistent chemical properties, they do not rapidly degrade and thus pose a potential health concern for reentry to suspect areas after an agent release.

Reproducible methods for detecting agents or their metabolites in plant or animal tissues or building materials have not been systematically established. The lack of rapid isolation techniques and low-level detection protocols has hindered development of civilian control limits for ingestion and dermal contact exposure to agents. As a result, there are currently no established analytical procedures for use in determining how long restricted public access to potentially agent-contaminated areas or agricultural resources should be maintained after release of a chemical warfare agent to the environment. Decision criteria for determining the extent and significance of potential agent contamination are needed to support several chemical warfare munition and materiel disposal activities. This logic is also needed for developing verification and compliance monitoring programs integral to the international Chemical Weapons Convention.

To support the development of environmental monitoring protocols and recovery phase planning efforts, the Office of the Assistant Secretary of the Army (Installations, Logistics and Environment) funded a multidisciplinary research program to address

1) biomonitoring of nerve agent exposure,
2) agent detection limits in meat, grain, vegetation and milk, and
3) permeation of chemical warfare agents through porous construction materials such as brick and wood.

Principal findings and applications are summarized below.

BIOMONITORING OF NERVE AGENT EXPOSURE

Biomonitoring capability by means of measuring the degree of whole blood cholinesterase (ChE) activity depression from baseline levels in sentinel livestock is potentially valuable as a biological check during routine facility operation, and as an indicator of the extent of nerve agent plume movement or deposition when timely deployment of low-level monitors is not feasible (Munro *et al* 1991). Monitoring of ChE activity could further serve as an indicator of the safety of previously contaminated areas for reentry by human beings, pets and livestock. This additional monitoring capability would augment present decision criteria that rely heavily on output from atmospheric dispersion models, which are limited by their 2-dimensionality and necessarily simplified assumptions (DA 1988).

In order for livestock ChE activity to be useful as a reliable biomonitoring end point, it is first necessary to characterize the sources of ChE variability in normal, healthy animals. This is a common principle that guides monitoring of ChE activity in the blood of agricultural workers exposed to organophosphate and carbamate insecticides during the growing season (Morgan 1989). The work reported here examined the effect of age, gender, reproductive status, state of health, time of day and season as sources of biological variability in several commercial livestock species (beef and dairy cattle, sheep, horses) that would be generally available for use as sentinel species in agricultural communities hosting chemical munitions stockpiles (Halbrook *et al* 1992a,b). These data, the first blood ChE-activity measurements to be systematically collected over at least one reproductive cycle (for approximately 12 months) from individual healthy animals, provide new information for assessing ChE-activity depressions in livestock blood. The research findings support the following recommendations for biomonitoring near any sites where nerve agents are stockpiled, or where nerve agents have been manufactured or processed (Chemical Weapons Convention treaty verification and compliance).

1) Repeated sampling of at least once a month for 6 months is necessary to establish a stable individual baseline of mean blood ChE activity for each animal within a sentinel group.

2) Adult animals should be selected as sentinels (ChE activity is partly a function of maturation).

3) The number of animals selected as sentinels is subjective, but should be no less than 6 adult animals of the same species for each monitoring area (defined as an area that individual sentinel animals would normally enter on a daily basis).

4) Collection and analysis of whole-blood samples for ChE activity determination should be performed at least monthly during the monitoring period (more often if events warrant).

5) Of the livestock species examined, domestic sheep are the preferred sentinel species due to the fact that they
   a. possess the least variable ChE activity within-individual and across age and gender groups,
   b. are relatively easy to handle and manage, and

c. cost less to purchase and maintain than cattle and horses

6) Refrigerate (at 4°C) blood samples and analyze within 24 hours of collection. If samples cannot be analyzed in this time period, store in liquid nitrogen (at -197°C).

AGENT DETECTION LIMITS AND RECOVERY FROM FOOD ITEMS

Research at Oak Ridge National Laboratory (ORNL) has demonstrated the efficacy of direct sampling ion trap mass spectrometry (ITMS) for the rapid and reproducible detection of target compounds, including chemical warfare agents, in environmental and physiological samples. The objectives of ongoing efforts are to combine the minimal sample preparation steps (needed to prevent tissue components such as proteins and fats from compromising instrument operation) with a rapid method of detecting low concentrations of target compounds (Caton *et al* 1994; Buchanan *et al*, in press). Extraction and analytical methods for chemical warfare agents were developed using agent simulants, which are less toxic chemical and physical analogues of actual chemical warfare agents. The simulant compounds employed were diisopropylmethyl phosphonate (DIMP; $C_7H_{17}PO_3$) for the nerve agent VX, and 2-chloroethyl ethyl sulfide (CEES, C_4H_9ClS) for the blister agent HD. Verification of the developed methods will require the use of "live" warfare agent compounds at certified surety facilities. To isolate simulant "spikes" to beef tissue, milk, wheat grain, and green alfalfa, a combination of centrifugation, filtration, dialysis, and adsorption onto solid phase sorbents was employed. Plant tissue proved to be problematic (Buchanan *et al*, in press). Depending on the extraction method employed, recovery rates for DIMP and CEES ranged from 50-85% (countercurrent filtration/dialysis followed by solid phase extraction) for meat, grain and milk; to 20-50% (solid phase extraction) for DIMP in meat and milk. For the sulfur mustard simulant CEES, recoveries were lower and more variable owing to the fact that CEES is more water soluble, more reactive and more volatile than DIMP. In all cases, thermal desorption ITMS proved to be a rapid and sensitive analytical procedure, with detection limits in the 50 to 100 ppb range.

Since these detection limits can be obtained with small initial sample sizes (100 mg), it is possible that this approach would be applicable to needle biopsy samples from living animals, rather than sacrificial testing. In addition, throughput is substantially increased because these new methods may be performed more quickly than conventional methods requiring substantial preparation (extraction into a suitable solvent followed by concentration via evaporation, etc.) and analysis times (combined gas chromatography and mass spectrometry).

PERMEATION OF CHEMICAL WARFARE AGENTS THROUGH CONSTRUCTION MATERIALS

There are presently no criteria suitable for designating potentially contaminated masonry, wood, wallboard or other "porous media" as free of hazardous agent concentrations. Concepts that have been previously considered include treating the suspect item or surface as if it were a piece of military hardware being prepared for sale to the public as scrap (DA 1992), wipe sampling of the suspect surface, or enclosing the item or area in an airtight manner followed by surface heating and airstream sampling. There are sampling and interpretation problems inherent to each of these approaches, not the least of which is how to determine acceptable agent concentrations for conditions of unlimited public access. Protocols for management of military scrap are the only U.S. guidelines governing agent decontamination of material that can be released to the public (DA 1992); these protocols were never intended for application to the treatment of public or private property under civilian, not military, control.

Experimental assessment of agent simulant "spike" sorption into, and permeation through, the porous construction materials brick, cinder block, gypsum wall board, and wood (with window glass as a non-porous reference medium) at two temperatures (23°C and 32.2°C) has now been performed (Jenkins *et al* 1994). Dimethylmethyl phosphonate (DMMP; $C_3H_9PO_3$) was the test simulant for nerve agent VX, while 2-chloroethylethyl sulfide (CEES; C_4H_9ClS) was the test simulant for the sulfur mustard agent HD. Note that, while the chemical structures of VX and DMMP are dissimilar, DMMP is frequently used an a physical analogue for VX because both compounds are phosphonates, and possess similar volatilities.

Simulant movement through wood was found to be nearly always in the direction of the wood grain. Two-dimensional breakthrough was observed in brick and gypsum wall board. All simulants permeated to the breakthrough space of gypsum wall board in a few hours, with CEES breakthrough more rapidly (< 1 hour) than other simulants. The sulfur mustard simulant broke through all test media in less than 60 min; nerve agent simulant breakthrough required several hours. All data indicate that substantial sample-to-sample variation in individual wafers of construction material exist, particularly for the coarsely porous brick and cinder block.

APPLICATIONS

Prudent host communities located near the stockpile sites have begun recovery phase planning. The results of the experimental program summarized above are included in the technical assistance currently provided to host communities by the authors. Examples of such assistance include:

Planning Guidance

Specific guidance is provided for recovery phase decontamination (of livestock and companion animals, personal and real property) and reentry (sampling and monitoring procedures, hazard assessment, access control). Checklists, fact sheets, material safety data sheets, pertinent technical articles, and prioritization schemes are recommended for inclusion in local emergency preparedness plans.

Recovery Plan Workbooks and Sourcebooks

These documents contain examples and necessary planning elements provided to host communities and stockpile installations for their use in developing coordinated recovery plans.

Recovery Phase Symposia

Site-specific symposia are presented within individual stockpile host communities. Approximately two full days are spent communicating monitoring and technical guidance for recovery phase planning with a broad cross-section of civilian and military emergency responders, planners, environmental regulators and agriculturalists.

Reentry/Restoration Tabletop Exercises

Recovery Phase TTX are held in "compressed" time mode as an adjunct to full scale exercises. Procedures to ensure the safety of the food supply (such as exclusion time intervals), determination of hazard zone boundaries, shelter-in-place alternatives, and the length of time necessary to provide mass care are discussed and developed.

Analytical Methods for Environmental Sampling Conferences

A technical conference has been useful as a means of fostering exchange among investigators and end users on current efforts to standardize analytical protocols for the reliable detection of chemical warfare agents and their degradation products in soil, vegetation and other complex environmental media.

CHALLENGES

Progress has been made in several recovery planning areas. However, there are still numerous challenges to be met. While there are promulgated agent control limits for chemical warfare agents in air, similar limits need to be established for other environmental media such as soil, water, milk and vegetation. As a parallel effort, the corresponding analytical methods (with detection limits) for assessing environmental media need to be documented.

Reliable monitoring of agent in environmental samples is a major concern of the U.S. Army Chemical Demilitarization and Remediation Activity, which has responsibility for non-stockpile chemical materiel (NSCM). The NSCM includes buried chemical warfare materiel (primarily in the 1950's and 1960's); recovered chemical weapons; former production, storage, and processing facilities for chemical weapons; and other agent auxiliary material defined in the international Chemical Weapons Convention. A timetable for destruction of these materials and certification of the suspect area as "clean" has been established, with the year 2000 as the first target date for one category of NSCM. Similar certifications are being imposed on U.S. military facilities by installation restoration and construction site clearance requirements, even though analytical verification procedures are still under development.

It is clear that similar needs for monitoring and detection protocols are being identified by U.S. military and civilian authorities as well as the international community concerned with chemical weapons treaty compliance and verification. Consolidated efforts would best serve resolution of these issues.

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URAL RIVER BENTHIC COMMUNITIES RESPONSE ON THE CHEMICAL SPILL

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KEYWORDS: benthic communities, chemical spills, pollution

ABSTRACT

An assessment of the Middle flow Ural River benthic communities by oil and phenols spill response is described. The paper is based on a study of the short-term response of benthic biocenosises compared with natural transformation of the community structure before pollution.

MATERIALS AND METHODS

Sediment and benthic samples were collected from the town of Orsk to the town of Novotroitsk 15-17 December 1991. The study areas are as follows: the Ural River waterway at 0.5 km up from Orsk's wastes water break collector of biodisposal station; the branch of the river at 0.5 km down from the collector; and the waterway near the water consumption stations of the Novotroitsk Metallurgical Works (about 15-18 km down from collector). Samples from the vicinity of the town of Novotroitsk were collected in 5-6 August 1991 too.

The 5-7 cm surface-sediment layer was sampled by quantitative bottom scraper (0.1 m2). The benthic animals were washed though a 0.6 mm sieve. The biodiversity of the fauna in each biocenosises was expressed as mean numbers of taxa per samples.

Maximov (1992) modified rank order method with dendrogram and graph interpretations were used for the analysis of the ecosystem state and its changes. These methods allow to the descrition of quantitative similarity of biocenosises structure and its transformations as a result of actions of natural and anthropogenic factors (Tarasov, 1993). So named "space-temporary elementary structures" (STES) of biocenosises on each station of sampling inscribed by four symbols (i.e. COpL or UptO) so named code "STES" of the biocenosis. The correlation matrix was calculated with the use of the programme ROMM version 1.2 (Y.M.Brumshtein and A.G.Tarasov, unpublished programme).

The balance of terms that we are using in this paper for descriptions of biocenosises at different levels of complexity are as follows: the biocenosis (communities) are included from one to few STES connect by measures of similarity (M) from 9 to 6; the form of dendrogram and graph are basis of separation of subbiocenosises and unification communities to superbiocenosis.

THE MIDDLE FLOW OF URAL RIVER CASE HISTORY

The Ural River is the second river of the North Caspian basin, on the north-west border of the Kazakhstan and Russian. The middle flow of the Ural River is limited by the dam of Iriklin water reservoirs (about 80 km up from Orsk town, Orenburg district) to the mouth of Barbastay River (about 45 km down from Ural'sk town.

On 13-17 November 1991, after an industrial incident in Orsk oil refinery enterprise effluent polluted the Ural River. The waste water was smell of carbonic acid and oil. The intermittent brown dense oil slick and iridescent sheer layer with brown spots were visible on the surface of the water for at least one day. The oil quantity on the water surface may be assessed from 0.98 to 1.95 ml/m^2 by Lesnikov (1974) visual scale.

Waste water from the river caused irritation of the skin and caused fish deaths. The oiled shore sediment, water-plant remains and hydrotechnical constructions were visible until the time of ice formation (i.e. about two weeks). The effluent included very high concentrations of phenols, hydrocarbons and other substances of oil processing. The contamination of phenols in the river water are from 0.680 to 0.002 mg/l. There as, the maximum of mean-monthly concentration of phenols (0.005 mg/l) in the period 1986-1990 was observed in March-April before flood-time.

BIODIVERSITY RESPONSE

The benthic macrofauna of the area 0.5-18.0 km down from the Orsk collector in December 1991 included only 18 pollution-tolerant taxa (Tab. 1). The toxicity tolerant organisms we know by data from Tauson (1955), Gromov, Demidova (1971) and many other authors.

There as, the benthos from station D1 (up from collector) included such pollution-sensitive organisms, as Simuliidae, Ortocladinae (Orthocladius gr. saxicola Kieffer, Cricotopus gr. algarum Kieffer) and Trichoptera (Hydropsyche ornatula McLachlan). These species were absent at all 0.5-18.0 km down.

The Bivalvia and Gastropoda mollusc remains were found in samples down from the collector. The shells were opened, and decomposed soft-body remains were observed inside shells. Obviously, these molluscs were smothered and killed by the effluent waters. Only two species (Lymnaea (Peregriana) ovata (Draparnaud) and Physa (Physa) adversa (E.M.Costa) from 28 mollusc taxa were not described earlier from this area, but these species had widespread distributions in waterbodies of the secondary hydrographic net of the Ural River, mainly in wetlands by our data (Pirogov et al., 1994). Seventy-seven taxa of macroinvertebrates were collected from the vicinity of Novotroitsk town before pollution.

CHANGES OF THE BOTTOM BIOCENOSISES AS CHEMICAL SPILL RESPONSE

The five groups of biocenosises were identified from the resulting dendrogram by data from the December sampling of benthos. The biocenosises from the polluted area had very low biodiversity and biomasses (Tab. 2). The distributions of the biocenosises of the Ural River waterway in suburbs of Novotroitsk are shown in the Figure 1.A.

The bidominant biocenosis of Chironominae and Oligochaeta occupied oiled muddy grounds of stretch of water (stations D14 and D15). The similar bidominant biocenosises with (sub)dominant Oligochaeta and Chironomidae were described by many authors for polluted sediments and unpolluted waterbodies of the Caspian basin. The similar community OC-- we separated by data Drabkin (1977) collected from the Ural River and its little tributaries in Orsk-Novotroitsk towns area in 1966 The level of water pollution of the Ural River in the 1960's according to the data of Dementev (1963) had high concentrations of hydrocarbons (0.35-0.60 mg/l) and phenols (0.2-0.3 mg/l). Oiled muddy sand from Volga delta in the 1970's and 1980's occupied oligodominant biocenosis Oligochaeta, Chironomidae and Lithoglyphus naticoides (C.Pfeiffer) (Tarasov et al., 1989). A similar type of weight distribution of two dominant groups (OC--) was described on oiled mud sediment by Konstantonov (1953) 8-10 km down from Saratov oil refinery enterprise. The mean biomasses of organisms corresponded to 0.537 and 0.001 g/m^2. Analogous transformations of bidominant biocenosises (OC--"CO--) may be separated by data of Tauson (1955) for the oiled muddy sediments of middle the un-named river that was the tributary of the Kama River in 40-120 km down from collector of coke-chemical enterprise. Unfortunately, she described abundance data only. The number of oligochaetes changed from 800 to 1200 ind/m^2, chironomides from 80 to 3500 ind/m^2, there as in Ural River about 18 km down from the Orsk industrial collector found from 30 to 70 ind/m^2 chironomides and from 10 to 30 ind/m^2 oligochaetes .

The chironomides and oligochaetes biocenosises were widespread on unpolluted sandy and gravelly bed load of the Vjatka River (unpublished data by author) and unpolluted muddy sediments of the Volga foredelta (Tarasov, Filchakov, 1994) by data authors and predecessors investigations. Often these structures transformed to oligodominant type.

The oiled gravelly-sand (sandy-gravel) and sandy sediments of shallow occupied similar bidominant biocenosis of larvae Chironominae and other Diptera (subdominant groups in this biocenosis changed from station to station or were absent, i.e. biocenosises reduced to monodomonant type). The similar type of biocenosises we described (Tarasov, 1993) from unpolluted sandy bed load of shallows of the Cheptsa River (tributary of Middle flow of the Vjatka). So-called "transit biocenosises" included some groups of organisms from drift in the different parts of square. Probably, that found mono- and bidominant biocenosises are the first step of recovery of bottom communities. For example, the STES of bidominant biocenosis from stations D7 assumed a character similar to STES biocenosis up from collector (station D1) and sample site D2 from river creek that down from wastes water break. The measure of similarity were corresponded from 6 (D1xD7) to 5 (D1xD2).

Five groups of stations were identified from the dendrogram on unpolluted sediment of the Ural River of the vicinity of Novotroitsk town in August 1991 (i.e. before pollution). These (sub)biocenosises had different quantity characteristics (Tab. 3, 4) and taxonomic structure (Fig. 1.B). The superbiocenosis included seven subbiocenosises were described on different types of grounds of shallow and stretch of water. The transformation of subbiocenosises structure was made by different type of sediment, water velocity, absence or presence of water-plant associations and their type. For example, the phytoreophilous biocenosis from station 3 (the naiads of Odonata as dominant, Oligochaeta - as subdominant of first rank) was connected with P. pectinalus and P. perfoliatus on compact mud sediment of shallow with very high current of water. The transformation of biocenosis structure in creek (station 10) and stretch of water (st. 14,15 and 15) from structure of biocenosises of shallow was the result of water velocity slowing, mud sedimentation and overgrowing by limnophilous water-plant.

The similar quantity distributions of organisms of different taxonomic level. Distribution of some benthic organisms had high level correlation that was marked on structure of biocenosises changes. For example, Valvatidae and Bithyniidae were included in dominant complex at least of four stations. The group of taxa Ortocladinae, Unionidae and Mysidae was identical to structure from station 17. After pollution were relations between benthic organisms disintegrated and high level correlation was marked only for very pollution-tolerant groups as Chironominae and Oligochaeta.

The changes of frequency distribution of ranks in correlation matrix after pollution show the disintegration of relations between "temporary elementary structures" of (sub)biocenosises. The increase of frequency indices of similarity M=4 and absence of measures of rank correlation from 9 to 7 reflects the simplicity of structure of bottom biocenosises and predominance of simple (mono-, bi- and oligodominant) communities with single dominant and different subdominants groups. The changes of simple temporary communities were described for bottom communities from polluted and very polluted areas of inland and brackish waters of Caspian sea basin (Gromov, 1954, Starostin, Tyrpaeva, 1967, Liperovskaja, Droshbina 1972).

The chemical pollution of water smothered and killed many groups of invertebrates and destroyed structure and lowered diversity of benthic biocenosises. However, natural decomposition of organic matters in black mud with hydrogen sulphide exuding on ox-bow lake (st. 8,9) smothered and killed benthos macroinvertebrates. The very high water velocity "blowouts" of surface-dwelling organisms and conducted to visual similar result (st. 7.1, 7.2).

However, we must note that difference in quality and quantity of characteristics of biocenosises down from Orsk industrial collector in winter and summer 1991 can not be explained by seasonal changes of bottom community. It was known that biomasses of benthos organisms in winter increased because the surface of bottom in winter regression of water level decreased (Drabkin, 1977). These literature describes are similar with data that we presents below.

Reconstructions of benthic community structure by Mollusca remains and biomasses of dominants groups showed that structures of bottom biocenosises from stations D14 and D15 were similar with pre-polluted stations 14 and 15 (Fig. 3, Tables 2 and 4). Reconstructions stricture subbiocenosises from bay with oiled muddy ground (st. D2) were similar with station of 10 unpolluted creek in August 1991.

The biocenosis from station D1 on the shallow up from collector attributed to polydominant type (Tab. 2). The biocenosises with similar structures had widespread distributions in the Ural River and similar streams (i.e. Cheptca River). For shallow of the Ural River in the vicinity of Novotroitsk in August 1991 we described similar STES of subbiocenosises (LCpK, CLvl, LCTK), they had measure of similarity (M) from 7 to 6. (stations 1, 4, 12 by Fig. 3).

Similar polydominant biocenosises with Ephemeroptera dominant, Chironomidae and Trichoptera subdominants were separated by data Drabkin (1977) collect from unpolluted area of the Ural River up from Orsk town in 1966 If dominant species (P. virgo and H. ornatula) in this biocenosis were similar with other parts of Ural River in middle 60-st (Drabkin, 1977), at that time M for two biocenosises (D1=3DLCHP and 1966=3DpCHO) were 5 i.e. they were almost identitical.

And so the biological methods based on characteristics of biodiversity of bottom fauna and assessments changes of structure benthic communities with using of Maximov modified rank order method with dendrogram and graph interpretations was be used for the analysis of the biocenosises changes as result oil and phenols spill. Only two types oligo- and bidominant biocenosises were marked on shallow and strench of water the Ural river in Orsk-Novotroitsk area after pollution, there as five polydominant subbiocenosises lived on area re-investigations in August 1991.

The assessment of biological response by method calculating ranks frequency distribution from correlation matrix needs addition testing.

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Table 1. Biodiversity of taxa macroinvertebrates found during the 1991 August (08) and December (12) Ural River survey

Taxonomic groups	Number of taxa		T.c.	B.c.
	before pollution	after pollution		
Oligochaeta	1 (classes)	1 (classes)	O	O
Hirudinea	2 (species)	2 (species)	Hir	-
Unionidae	4 (species)	0 (species)	U	U
Pisidioinei	14 (species)	4d (species)	-	P
Sphaeriidae	2 (species)	1d (species)	Sph	-
Pisidiidae	4 (species)	1d (species)	Ps	-
Euglesiidae	8 (species)	2d (species)	Eu	-
Valvatidae	3 (species)	1d (species)	v	v
Bithyniidae	1 (species)	0 (species)	b	b
Lymnaeidae	2 (species)	2d (species)	l	l
Physidae	2 (species)	1d (species)	Ph	@
Planorbidae	2 (species)	1d (species)	Pl	@
Malacostraca	1 (species)	0 (species)	m	m
Heteroptera	1 (species)	0 (species)	A	A
Odonata	4 (species)	2 (species)	c	c
Ephemeroptera	6 (species)	1 (species)	Eph	-
P. virgo	+	-	-	p
C. macrura	+	+	-	K
Ameletus sp.	+	-	-	a
Trichoptera	2 (species)	0 (species)	Tr	-
H. ornatula	+	-	-	H
Coleoptera	1 (genus)	1 (genus)	Col	-
Chironomidae	* (species)	* (species)	-	e
Ortocladinae	6 (species)	0 (species)	Ort	-
Tanipodinae	4 (species)	1 (species)	Tn	-
Chironominae	14 (species)	8 (species)	C	C
Other Diptera	7 (families)	3 (families)	D	-
Limonidae sp. sp.	+	+	-	L
Tabanidae sp. sp.	+	-	-	T
Tipulidae sp. sp.	+	+	-	t

Notes: d - smothered and killed by the effluent waters (decomposed soft-body remains observed inside shells); abbreviation. Taxonomic (T.c.) and biocenosis (B.c.) codes.

Table 2. Biomasses dominant and subdominant groups of bottom biocenosis from Orsk-Novotroitsk towns area in December 1991 (g/m^2, m±CD)

Ranks j	Biocenosis and subbiocenosises					
	Stations					
	D1	D2	D2^r	D7, D11, D13 D16.1, D17	D14, D15	D14^r, D15^r
	LCHP	cLC-	Pcbv^r	C+--	CO--	bvlC(O)^r
D	6.83	4.46	~6.89	0.03± 0.02	0.39± 0.28	3.32± 1.38
Sd1	0.49	3.87	~4.46	0.01± 0.02	0.35± 0.30	1.50± 0.99
Sd2	0.30	0.71	~4.20	-	-	0.40± 0.29
Sd3	0.06	-	~3.87	-	-	0.39± 0.28
Sd4	0.04	-	~2.81	-	-	0.35± 0.30
n	11.00	8.00	>16.00	1.50± 0.50	2.00± 0.00	>9.00

Notes: D - dominant, Sd - subdominant groups, n - number of taxa. r - reconstructions structure and data.

Table 3. Biomasses dominant and subdominant groups of bottom biocenosis on "coarse" sediment of the Ural River from vicinity of Novotroitsk town in August 1991 (g/m^2, m±CD)

Ranks j	Biocenosis and subbiocenosises				
	Stations				
	1, 4, 11, 12	2, 13	3	10	17
	CLKt(v)	CKOP(p)	COpL(K)	PbVO(K)	UptO(P)
D	1.80± 0.53	8.84± 7.94	8.47	4.25	1052.70
Sd1	2.77± 2.55	1.12± 0.96	0.99	3.49	3.22
Sd2	0.29± 0.33	0.72± 1.05	0.58	3.17	1.00
Sd3	0.21± 0.41	0.48± 0.67	0.54	2.70	0.81
Sd4	0.06± 0.10	0.37± 0.53	0.50	1.83	0.39
n	16.00± 2.00	19.00± 2.00	17.0	23.00	21.00

Notes: D - dominant, Sd - subdominant groups, n - number of taxa.

Table 4. Biomasses dominant and subdominant groups of bottom biocenosis on "soft" sediment of the Ural River from vicinity of Novotroitsk town in August 1991 (g/m^2, m±CD)

Ranks j	Biocenosis and subbiocenosises		
	Stations		
	5, 7	14, 15, 16.1	6, 16
	LtCc(A)	vbcC(l)	lvcC(O)
D	3.82± 1.51	3.83± 1.31	9.29± 0.96
Sd1	3.36± 3.02	2.24± 1.58	2.38± 1.72
Sd2	1.26± 1.28	1.17± 0.91	2.43± 2.12
Sd3	1.08± 1.53	1.37± 2.31	3.72± 5.14
Sd4	0.69± 0.10	0.29± 0.25	0.56± 0.77
n	17.00± 0.00	14.00± 2.00	23.00± 3.00

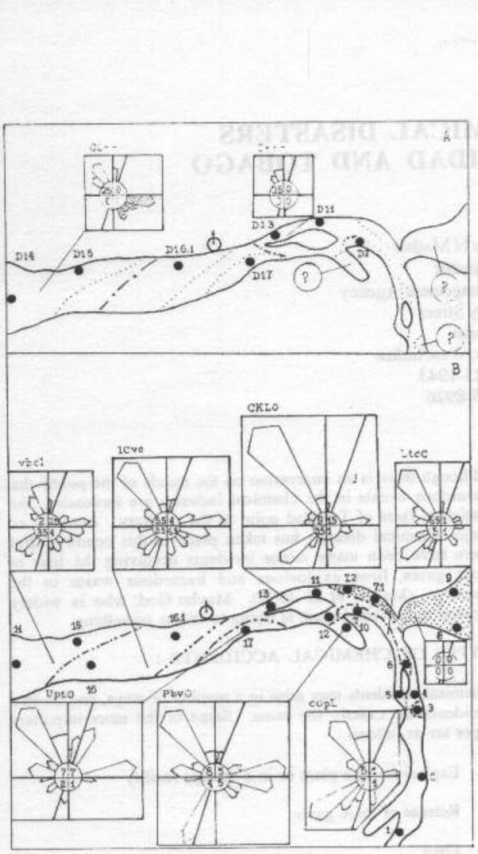

Figure 1. Vicinity of Novotroitsk town, showing location Water Consumption Station of NOSTA, study sites and distribution of bottom biocenosises and subbiocenosises. A. in December 1991 B in August 1991 Showing native organisms and died Mollusca with decomposed body remains inside shells (for sites of sampling D14, D15). The bordies of biocenosises (-*-) and subbiocenosises (-**-) and its structure. See Fig. 2 and Tab.1 for additional taxonomic details.

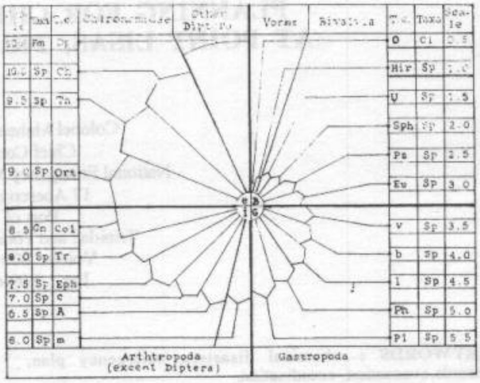

Figure 2. Taxonomic structure of bottom biocenosises and subbiocenosises. Showing: in centre of round: B - mean number species of Bivalvia per samples. G - mean number species of Gastropoda per samples. I - mean number taxa of Insecta (excluded Diptera) per samples. c - mean number species of Chironomidae per samples. See Tab.1 for additional taxonomic details.

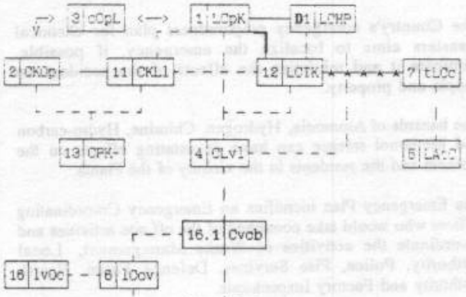

Figure 3. Graph of the route of maximum correlation with additional relations of biocenosises structure. Showing M (measures of similarity) from 8 to 5 by biomasses (Mb) and abundance (Ma) characteristics. See Fig. 2 and Tab.1 for additional codes of biocenosises structure.

PLANNING FOR CHEMICAL DISASTERS AT POINT LISAS, TRINIDAD AND TOBAGO

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KEYWORDS : chemical disasters, emergency plan, hazards, evacuation, coordination.

ABSTRACT :

No major chemical disaster has taken place so far in Trinidad and Tobago. Even so, in view of the numerous hazards that the various chemical handling plants deal with at Point Lisas, the Country has to be prepared to deal with chemical disasters.

The Country's emergency preparedness plan for chemical disasters aims to localize the emergency, if possible, eliminate it and minimize the effects of the accident on people and property.

The hazards of Ammonia, Hydrogen, Chlorine, Hydro-carbon and Methanol release can have devastating effects on the workers and the residents in the vicinity of the Plants.

The Emergency Plan identifies an Emergency Co-ordinating Officer who would take command of the off-site activities and co-ordinate the activities of Works Management, Local Authority, Police, Fire Services, Defence Force, Health Authority and Factory Inspectorate.

Resources of fire fighting, medical treatment, telecommunications, waste management and public education have to be enhanced immediately. In the long term a new fire station and a new county hospital have to be built, some housing settlements have to be phased out and non-essential staff relocated.

INTRODUCTION :

> ***"The wise man will rule over planetary influences, which do not necessarily bring their properties to bear upon terrestrial bodies; but he only influences the latter, because it is possible to protect oneself through prudence and discretion."***
>
> **Ptolemy**

It has been said that God often tries us with a little to see what we could do with a lot. (McKenzie 1980).

Although there is an impression on the minds of the public that hazardous events in the chemical industry are increasing, the statistical facts of Trinidad point to the contrary. Actually no major chemical disaster has taken place in this country. But there have been many minor incidents involving the leak of toxic gases, fires, explosions and hazardous waste in the country. (Mathur *et al.* 1992). Maybe God, who is widely reputed to be Trinidadian, is trying to tell us something.

TYPES OF CHEMICAL ACCIDENTS :

Chemical accidents may arise in a number of ways, and no two accidents are exactly the same. Some of the more important types are as follows :

a) Explosions in a plant or in a storage facility

b) Release of toxic gases

c) Fires

d) Accidents during the transportation of chemicals

e) Improper waste management

The safety record in Trinidad, as far as we have been able to determine, is dependant upon the maintenance of the strictest safety regulations and accident prevention through staff training. It is instructive that all major accidents around the world involving chemical storage and manufacture had human failure as the root cause of the problem. Let us consider two case studies in different parts of the world and examine the lessons drawn from them.

CASE STUDIES :

PEMEX - Mexico City : This is a state-owned oil company which operated an LPG (Liquefied Petroleum Gas) storage and distribution centre.

On November 19, 1984 an explosion at the factory killed 542 and injured 4000. At that time this was the most serious chemical industry accident. It held this record for 2 weeks only. Bhopal happened on December 3, 1984.

It seems that there was a leak in a 20 cm feed pipe to the storage tanks. At 0530 hours the LPG escaped with a deafening noise.

There was a slight breeze and the gas cloud moved south-west over an area about 200 x 150 metres. One edge of this cloud reached a residential area. Another edge was drifting towards a flare on the site. There was a village downwind of the site towards which the cloud of gas, about 2 metres high, was drifting at about half a metre a second. At 0540 hours the gas cloud reached the flare and ignited. There was an immediate and explosive conflagration engulfing both the Plant and the village.

The initial explosion ruptured exposed piping which increased the volume of gas released and fueled the fire. Successively other storage tanks exploded raining burning gas, red hot metal and liquid gas to distances as much as 600 metres from the Plant.

In all, nine explosions were recorded between 0530 and 0730 hours, two of them powerful enough to be recorded on earthquake measurement instruments 25 km away.

Devastation was complete out to 300 metres from the Plant perimeter fence. Two thousand houses were destroyed as far out as 400 metres from the site.

Both the police and the emergency services were aware of two similar plants nearby to which PEMEX distributed LPG by underground pipeline. Indeed, the main office of one of these plants was demolished by a 40 tonne piece of metal hurled by one of the explosions. Fortunately, due to adequate protection of the tanks on this site, they were not ruptured.

At the third Plant, nearly one hundred trucks loaded with household gas cylinders were totally destroyed by fire. (Cranfield 1990).

Bhopal : Bhopal is a city of 800,000 in Central India. In 1934, Union Carbide, a major multi-national chemical manufacturer established a plant in the city. 1984 was its Golden Jubilee year.

On December 3, 1984 a man-made accident at the plant caused the greatest industrial accident known. Over 3000 were left dead, killed by toxic fumes and as many as 250,000 suffered permanent disability in sight, breathing and general physical or mental health.

As so frequently happens in chemical disasters, there was little the emergency services were able to do to rescue survivors other than assist a very small proportion to hospital.

A study of the events leading up to and subsequent to the disaster does, however, contain a number of lessons (Varadarajan *et al.* 1985) :

- Due to faulty engineering and operating (washing out pipes), water got into the system where it should not have been and caused a chemical reaction.
- Chemicals were stored in far greater quantities than were necessary for production.
- When the accident happened, the Union Carbide staff took themselves up-wind to safety and took no preventative or remedial action.
- A siren was sounded. Because the local people had no knowledge of the warning system or what they should do, they rushed into the street and even towards the plant to help fight what they thought was a fire.
- None of the plant safety devices worked.
- Operating and Safety Manuals were not being observed although developed in consequence of a serious accident in 1982.
- The local authorities had never been advised of the hazards so that they could plan against such an emergency.
- In 1934 the Plant was outside the Bhopal City. Over the next five years residential areas spread out to the Plant and the area became densely populated.
- In 1975 the Administrator of Bhopal told Union Carbide to move the Plant. The Plant stayed, the Administrator was transferred, Union Carbide donated US$2000 for a public park and the notice to move was withdrawn. In 1979/80 the Plant began manufacture of the deadly MIC (Methyl Icocyrate).

CABINET APPOINTED COMMITTEE :

It was not too soon that the Cabinet of Trinidad and Tobago decided last year to appoint a permanent committee to evaluate and plan for disaster preparedness at Point Lisas including community awareness programmes. Chairman of this committee is the Chief Co-ordinator, National Emergency Management Agency (NEMA), while the membership comprises representatives from the Trinidad and Tobago Police Service, Fire and Ambulance Service, Defence Force, Ministry of Energy and Energy Based Industries, Point Lisas Industrial Port Development Corporation Limited (PLIPDECO), Inter Enterprise Safety Advisory Committee, Trinidad and Tobago Emergency Mutual Aid Scheme (TTEMAS), Ministry of Health, and Factory Inspectorate. We have co-opted a member of the Local Government to the Committee.

FORMULATING THE PLAN :

Objectives :

The overall objectives of the Emergency Plan are :

a) To localize the emergency and, if possible, eliminate it, and

b) To minimize the effects of the accident on people and property. (OECD 1992).

IDENTIFICATION AND ASSESSMENT OF HAZARDS :

This stage was crucial to both on-site and off-site emergency planning and requires Works Management to systematically identify what emergencies could arise in their plans. We visited various industries at Point Lisas to get first hand information on the hazards at each plant and identified the following hazards :

a) **Release of Ammonia :**

This situation can result from storage tank failures at the three Ammonia Plants located on the Estate - FERTRIN, HYDRO AGRI and TRINGEN - and ammonia can also be released from pipelines. Because of its toxic nature and because it is also flammable, ammonia also poses threats of fire and explosion.

b) **Release of Hydrogen :**

This situation can result from leakage in the steam reformer at FERTRIN, the two Methanol Companies, Hydro Agri Company Limited and TRINGEN. Leaking lines may also result in a release of hydrogen. Hydrogen ignites and burns rapidly and it also presents an explosion hazard. Since the flame is non-toxic, it may not be visible.

c) **Release of Chlorine :**

This situation can occur as a result of storage tank failure at the Chlorine Plant on the Estate. This release is potentially one of the most severe hazards presented by the Chemical Industry.

d) **Hydro-Carbon Release :**

This can occur as a result of a natural gas release. The hydro-carbons are flammable and give rise to hazards both of fire and of toxic release.

e) **Release of Methanol :**

This can result from a failure of the large vessels at either of the two Methanol Plants. The releases may also be as a result of line breakage or line leakage. Methanol also presents a fire hazard and burns with a non-luminous flame which is difficult to see. (Boodoosingh 1993).

ASSESSMENT OF RISKS :

The aim at this stage of the hazard evaluation process is to establish what is the likelihood of hazards being manifested, and how the accident would affect the vulnerable areas.

The following conclusions can be drawn from the studies made so far :

a) The potential is there for the occurrence of a major chemical disaster at the Point Lisas Industrial Estate.

b) Catastrophic failure of process equipment, pipelines or storage vessels can result in devastating effects both on the workers and the residents in the vicinity of the Plants.

c) Some of the housing settlements are definitely too close to the Estate. These settlements include Brechin Castle, Couva, Couva Housing Settlement and California.

d) There may not be enough time to evacuate the Estate and surrounding settlements should the release of chemicals occur. Six thousand employees and 17,615 people in surrounding areas may be involved.

ON-SITE EMERGENCY PLANNING :

Most of the Plants have their own Disaster Preparedness Plans. Generally, the plans are in the following four sections :

i) General information which gives site manning and community population and site operations.

ii) Possible emergencies and hazards.

iii) The individual responsibilities for emergencies.

iv) General information for handling injuries, radio communications, traffic control and telephone systems.

The primary purpose of the on-site emergency plan is to control and contain the incident and to prevent it from spreading to nearby Plants.

OFF-SITE EMERGENCY PLANNING :

The off-site emergency plan is an integral part of our major hazard control system. It is based on those accidents identified by the Works Management which could affect people and the environment outside the works. Thus, the off-site plan follows logically from the analysis that took place to provide the basis for the on-site plan and the two plans should, therefore, complement each other. The off-site plan in detail is based on those events which are most likely to occur, but other less likely events which would have severe consequences have also been considered. The key feature of a good off-site emergency plan is flexibility in its application to emergencies other than those specifically included in the formation of the plan.

The plan identifies an Emergency Co-ordinating Officer who would take overall command of the off-site activities. As with the on-site plan, an Emergency Control Centre is required within which the Emergency Co-ordinating Officer can operate.

An early decision will be required in many cases on the advice to be given to people living "within range" of the accident - in particular, whether they should be evacuated or told to go indoors. In the latter case, the decision can regularly be reviewed in the event of an escalation of the incident. Consideration of evacuation may include the following factors :

a) in the case of a major fire but without explosion risk, eg, an oil storage tank, only houses close to the fire are likely to need evacuation, although a severe smoke hazard may require this to be reviewed periodically;

b) if a fire is escalating and in turn threatening a store of hazardous materials, it might be necessary to evacuate people nearby, but only if there is time; if insufficient time exists, people should be advised to stay indoors and shield themselves from the fire. This latter case particularly applies if the installation at risk could produce a fireball with very severe thermal radiation effects, eg, LPG storage;

c) for releases or potential releases of toxic materials, limited evacuation may be appropriate down wind if there is time. The decision would depend partly on the type of housing "at risk". Conventional housing of solid construction with windows closed offers substantial protection from the effects of a toxic cloud, while shanty houses offer little or no protection.

The major difference between releases of toxic and flammable materials is that toxic clouds are generally hazardous down to much lower concentrations and, therefore, hazardous over greater distances. Also, a toxic cloud drifting at, say, 300 metres per minute covers a large area of land very quickly. Any consideration of evacuation must take this into account. (Farabi 1991).

ROLE OF THE EMERGENCY CO-ORDINATING OFFICER :

The various emergency services are co-ordinated by an Emergency Co-ordinating Officer (ECO) who is a senior Fire Officer. The ECO will liaise closely with the Site Main Controller. Again, depending on local arrangements, for very severe incidents with major or prolonged off-site consequences, the external control may pass to the National Emergency Management Agency (NEMA).

ROLE OF MAJOR HAZARD WORKS MANAGEMENT :

The role of the Works Management in off-site emergency planning will be to maintain liaison with the Cabinet Appointed Committee to provide information appropriate to such plans. This will include a description of possible on-site accidents with potential for off-site harm, together with their consequences and an indication of the relative likelihood of the accidents.

Advice should be provided by Works Management to all the outside organizations which may become involved in handling the emergency off-site, and which will need previously to have familiarized themselves with some of the technical aspects of the works activities, eg, emergency services, medical departments and also water authorities (if water contamination could be a consequence of an accident).

ROLE OF THE LOCAL AUTHORITY :

The local corporation has appointed an Emergency Planning Officer (EPO) to carry out this duty as part of the EPO's role in preparing for a whole range of different emergencies within the local authority area. The EPO will need to liaise with the works to obtain the information to provide the basis for the plan. This liaison will need to be maintained to ensure that the plan is continually kept up to date.

It will be the responsibility of the EPO to ensure that all those organizations which will be involved off-site in handling the emergency know of their role and are able to accept it by having, for example, sufficient staff and appropriate equipment to cover their particular responsibilities.

Rehearsals for off-site plans are important for the same reasons as on-site plans and need to be organized by the EPO.

ROLE OF THE POLICE :

Formal duties of the Police during an emergency include protecting life and property and controlling traffic movements.

Their functions include controlling bystanders, evacuating the public, identifying the dead and dealing with casualties, and informing relatives of death or injury.

ROLE OF THE FIRE AUTHORITIES :

The overall control of an emergency will be assumed by the Fire Service, with a senior officer designated as Emergency Co-ordinating Officer.

The control of a fire is normally the responsibility of the Senior Fire Brigade Officer who would take over the handling of the fire from the Site Incident Controller on arrival at the site. The Senior Fire Brigade Officer may also have a similar responsibility for other events, such as explosions and toxic releases. Fire authorities would familiarise themselves with the location on-site of all stores of flammable materials, water and foam supply points, and fire-fighting equipment. They may well have been involved in on-site emergency rehearsals both as participants and, on occasion, as observers of exercises involving only site personnel.

ROLE OF THE DEFENCE FORCE :

Defence Force is assigned the duties of search and rescue of the victims and providing additional transport for evacuation of victims and those threatened by the disaster.

ROLE OF THE HEALTH AUTHORITIES :

Health authorities, including doctors, surgeons, hospitals, ambulances and so on, have a vital part to play following a major accident, and they would form an integral part of any emergency plan.

For major fires, injuries will be the result of the effects of thermal radiation to a varying degree, and the knowledge and experience to handle this in all but extreme cases may be generally available in most hospitals. For major toxic releases the effects vary according to the chemical in question, and it is important for health authorities who might be involved in dealing with the aftermath of a toxic release to be familiar with the treatment appropriate to such casualties.

Major off-site incidents are likely to require medical equipment and facilities additional to those available locally, and a medical "mutual aid" scheme should exist to enable the assistance of neighbouring authorities to be obtained in the event of an emergency.

The local Couva District Hospital would be used as a first stage Management Unit.

ROLE OF THE FACTORY INSPECTORATE :

In the event of an accident, the Factory Inspector will have a close involvement in advising on operations. In cases where toxic gases may have been released, the Factory Inspectorate may be the only external agency with equipment and resources to carry out tests.

In the aftermath, the Factory Inspector may wish to ensure that the affected areas are rehabilitated safely. In addition, they may require items of plant and equipment essential for any subsequent investigation to be impounded for expert analysis, and may also want to interview witnesses as soon as practicable.

REHEARSALS AND EXERCISES IN OFF-SITE EMERGENCY PLANNING :

Extensive experience in the chemical industry with on-site emergency planning has proved the need and value of rehearsals of emergency procedures.

NEMA would test the off-site plan in conjunction with on-site exercises. Table-top rehearsals are also extremely useful in such cases.

An essential component of any trial is that of testing fully the various communication links necessary to gather the information needed for overall co-ordination, eg. between works and emergency services, and between the works emergency control centre and the incident.

Trinidad and Tobago Emergency Mutual Aid Scheme (TTEMAS), which involves most of the industries located at Point Lisas, is well placed to advise on the setting up of rehearsals and particularly to advise on the scope for an escalation in the degree of emergency.

IMMEDIATE MEASURES :

Fire and Emergency Unit :

It is proposed to acquire appliances and equipment worth approximately TT$14 million for dealing with the Point Lisas Industrial Estate. This equipment would be located at Chaguanas Fire Station until the Fire Station is built at Point Lisas.

Medical Facilities :

Setting in place arrangements with PETROTRIN for the use of the Augustus Long Hospital for receiving, treating and caring for industrial casualties. It will be necessary to establish a specialized de-toxification, poison control, burn therapy and industrial trauma care unit at these facilities.

Telecommunications :

The Telecommunications Division in the Office of the Prime Minister will design a communications system for efficient command and control in emergency situations. The system will be reinforced by the mobile sets from the Defence Force.

Waste Management :

Manufacturing companies to ensure disposal of hazardous solid waste at Forres Park Site in consultation with Solid Waste Management and treat / separate liquid waste before discharge into the waterways.

Public Education :

The public education programme would be undertaken to inform the public of the hazards present at Point Lisas Estate and the Outline Emergency Plan. This would take the form of workshops and seminars to inform the public concerned about the actions which they would take. Media would also be involved in this exercise.

Legislation :

Enactment of legislation should be done for minimizing risk of technological disasters and adoption of international standards, codes and practices. (Health and Safety Executive 1990).

LONG TERM MEASURES :

- Construction of a new Fire Station suitably designed to include Observation Tower, Control Room facility and Seal-Proof interior.
- Expediting construction of a County Hospital in Couva, feasibility study for which is currently taking place.
- Phasing out of residential buildings at California, Couva Housing Settlement and Brechin Castle.
- Relocation of non-essential staff of various manufacturing companies beyond 1.9 km radius of the Estate.

Security of operations outside the fence should be considered critical and should be immediately addressed by Point Lisas Industrial Port Development Corporation (PLIPDECO) in conjunction with the Police. (Mathur *et al.* 1994).

CONCLUSION :

The initial management of chemical accidents requires a thorough knowledge of properties of materials, their reactivity under varied conditions, the circumstances of the accident, estimate of nature and quantity of various products released and their effects on life systems and environment. The relief measures depend largely on such knowledge. Containment of toxic material, disposal and decontamination again demand a multi-disciplinary approach.

With the growth in volume and variety of chemicals produced at Point Lisas, much greater care is required in operation and maintenance of plants than ever before. Open discussion and disclosure by technologists and manufacturing units are urgently needed to ensure greater safety.

A fund has to be established immediately at Point Lisas Industrial Port Development Corporation (PLIPDECO) to implement the Outline Emergency Plan and short term plan. Once the Corporations at Point Lisas demonstrate their commitment to emergency planning, I am confident the Government will chip in to assist in the Long Term Planning for emergency management.

For too long we, the Government and Industry have been keeping our fears to ourselves. The time has now come to share each other's burden. All of us will then be able to walk a little straighter.

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BIOGRAPHY :

Colonel Mahendra Mathur served in the Corps of Engineers of the Indian Army for 21 years before coming to Trinidad and Tobago to build the Claude Noel Highway in Tobago in 1975.

On completion of the highway, Colonel Mathur was appointed Technical Officer in the Ministry of National Security with responsibility for all engineering works in support of the Defence Force, Police, Fire and Prisons Services.

When the National Emergency Management Agency (NEMA) of Trinidad and Tobago was set up on 1 May 1989, Colonel Mathur was asked to head it. Initially, Colonel Mathur's responsibilities were confined to national disasters. Since 1993 he has also been entrusted the responsibility of planning for chemical disasters.

PROGNOSIS MODELS OF HUMAN INJURY IN CHEMICAL DISASTERS

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KEYWORDS: chemical disasters, human injury, toxic doses, mathematical models

ABSTRACT

Mathematical models are described for predicting the human injuries resulting from toxic chemical disasters.

In the case of chemical disasters it is very important to determine the resources (medical personal, medicines, equipment, transport) necessary for rendering of medical aid to casualties .

Advance forecasting of the number and structure of casualties helps to resolve this problem.

As a matter of fact, we may give a quantitative characteristic of damage to the health of persons and we may receive the opportunity of doing a prognosis of the appearance of a certain quantity of fatal outcomes and injuries (including the degree of severity of affect) during a disaster in a chemically dangerous object only if we are able to answer the question: what will happen with one person or with a group of persons who found themselves at a certain distance from the source of the accident and who were affected with the poison substance. It will be possible to answer this question if we are able to create models of injury to people who were situated in the area of dangerous effect of the toxic agents.

The analysis of this problem shows that the solution of this task is possible on the basis of consolidation of the law-governed nature of atmospheric diffusion of gases, the methodical approach of general theory of damage to the organism, the dependencies of the toxic action of substances, and consideration of the character of the accident and the peculiarity of toxic agent spreading in the atmosphere.

Our view is that the main position concerning this problem is utilization of the methodology of general theory of damage and, on this basis, the creation of a parametric law of toxic injury to persons.

Parametric laws (functions of injury) give the opportunity to describe the direct action of the injurious factor to persons and they show the dependence of probability of injury on the certain degree of severity from the parameters of the injurious factor.

Inhalation injury from gaseous poisonous substances is characterized by parameters determining the quantity of the approaching effect, and these parameters express the concentration of the substance in the environment and the time of its action. Let us see the dependence of toxic injury effect from the concentration of the substance and the time of exposure. Practical observations show us that if the concentration is higher and the time of its action is longer, the effect which they cause is higher also.

The relationship between the concentration of the poison, the time of its action and the effect in case of its inhalation was substantiated by the well-known German toxicologist F. Haber (1924) at the beginning of this century. This generalization is known as the rule of Haber:

$$W = C \cdot t = const \qquad (1)$$

The value W Haber named as "the quantity of the effect". The Soviet toxicologist N. Lazarev named $C \cdot t$ as "the toxic coefficient." Scientists today call it "the toxic load," but in Russian scientific literature the product $C \cdot t$ is called "toxodose".

J. Withers (1985) and other scientists assert that the relationship between concentration and time of exposure is described by the following formula:

$W = C \cdot t^{n}$, where usually $n < 1$ (2)

The use of the value $C \cdot t^{n}$ to appreciate the injurious effect of a substance is proposed by these authors in the theoretical plan and implies the use of a log-normal distribution:

$$F = \frac{1}{2\pi\sigma} \int_{0}^{\infty} \frac{1}{x} \exp\left[-\left(\lg x - m^{*} \right)^{2} / 2\sigma^{2} \right] dx$$

where $\dot{m}$ is the parameter of the distribution (but, unfortunately , its value is not given).

We suggest using the toxic dose received by a person and the time during which this toxic dose was received, but not the concentration and the time of exposure, as the main parameters.

Let us consider the concept of toxic dose. We suggest using the concept of doses absorbed by the organism, which was formulated by F. Flury, but we don't use the above mentioned "pseudo-dose" - the product $C \cdot t$ and $C \cdot t^{n}$.

Flury suggested this formula:

$$D = V \cdot C \cdot t \qquad (3)$$

where D - the absorbed toxic dose; V - the volume of the pulmonary ventilation; C - the concentration of the substance; t - the time of exposure.

Thus, we may come to a level other than the level of concentration and conditional doses. In this case we may use the arsenal of biometrical approaches which is accumulated in radiobiology to appreciate the effect of the dose.

Unfortunately, the accessible literature doesn't give us information about the dependence of absorbed toxic dose from the time of exposure. To describe this dependence let us see the formula 2:

$$W = C \cdot t^n = const$$

Concretizing, we may write:

$$C_1 \cdot t_1^n = C_2 \cdot t_2^n$$

Let us multiply two parts of this equation on the value of the volume of pulmonary ventilation, then we present t^n as $t \cdot t^{n-1}$ and we have:

$$V \cdot C_1 \cdot t_1 \cdot t_1^{n-1} = V \cdot C_2 \cdot t_2 \cdot t_2^{n-1}$$

Let us designate the product $V \cdot C \cdot t$ as toxic dose D, so we see:

$D_1 \cdot t_1^{n-1} = D_2 \cdot t_2^{n-1}$, consequently,

$$D_1 = D_2 (t_2 / t_1)^{n-1} \qquad (4)$$

Generalizing equation 4, we may assert that having determined the toxic dose once (let us call it D_0) which characterizes the effect of interest, we may find the effective toxic dose D_{eff} (which is very interesting for us and which causes this effect) for any time of exposure t:

$$D_{eff} = D_0 (t_0 / t)^{n-1} \qquad (5)$$

As D_0 we may use the value of the toxic dose, which can be calculated on the basis of lethal concentration LC_{50} (let us call it "$C_{letha(0)}$, $C_{lth(0)}$"), which we can find in the literature, and the corresponding value of the time of exposition (let us call it "$t_{lth(0)}$"):

$$D_{lth(0)} = V \cdot C_{lth(0)} \cdot t_{lth(0)} \qquad (6)$$

Now we have found the equation for calculating the lethal toxic dose, i.e. that index which characterizes the death of persons. Effective lethal toxic doses which were calculated with the help of real data are, for example, for chlorine - 180 mg, for ammonia - 3000 mg.

But, besides dead persons, during chemical disasters we have a great amount of victims who need medical aid.

At present we use a classification of human injury according to the degree of severity: the first group - injuries of light degree; the second group - injuries of medium degree; the third - severe injuries.

To calculate the toxic dose characterizing injury of light degree we may use the formula 3 and the data of the injurious concentration - IC_{50} (I - incapacitating) and the corresponding values of exposure:

$$D_{ligh(0)} = V \cdot C_{i(0)} \cdot t_{i(0)} \qquad (7)$$

where C - the injurious concentration; t - the time of exposure.

This approach is legitimate, because we understand the injurious concentration (IC_{50}) as the value of the concentration which doesn't cause the symptoms of injury in 50% of persons, but which causes injury of light degree in the other 50% of persons who were in the contaminated area with the given concentration of toxic agent.

Then we need to determine the threshold values of toxic doses for injuries of medium and severe degrees. For this case it is necessary to get experimental data and then to use probit analysis.

But we have another way of determining the threshold values of toxic doses for these injuries, even if we have no experimental data. The construction of mathematical models of injury to the population is connected with the necessity of the formalization of ideas concerning the structure of the human organism.

Let us use models of injury to persons which are based on the formal ideas considering the organism of a man as a total combination of functional systems and considering the mechanism of damaging of these systems. These models were substantiated in research in radiobiology.

In coordination with the essence of these models the acceptable approximation of the parametric law of injury is Weibull's distribution:

$$F(z(x,y)) = 1 - exp\left[-(\beta_\gamma \cdot U_i)^\gamma\right] \qquad (8)$$

where β_γ, γ - the parameters of distribution of Weibull, characterizing certain effect (level of injury); U_i - the complex fixed parameter of injury.

The parameter of injury U_i (for i - the severity of injury: light, medium, severe, death) is determined as the ratio of the value of the dose of the really acting factor of the injury to the predefined effective value of the dose of the injurious factor which characterizes this effect (level) of the injury.

The value of parameters of the distribution of Weibull for the different degrees of severity of the injury, according to the data of G. Maximov (1983), are shown in Table 1.

According to the above-mentioned analogy we suggest using the distribution of Weibull to describe the levels of injury during the inhalation influence of a poisonous substance on the population during a chemical disaster. We think that this approach is justified, because it's based on the hypotheses of the determination of injury, which tells that a certain degree of severity of injury occurs when a certain number of "systems" of an organism are injured.

So we may use values β_γ and γ , which we see in Table 1. Now we are going to determine the essence of the parameter U_i . In our case the parameter U_i is the ratio of the toxic dose received (absorbed) in this concrete case D_{abs} , to the predefined toxic dose which causes a certain effect of injury $D_{eff(i)}$:

$$U_i = \frac{D_{abs}}{D_{ef(i)}} \qquad (9)$$

Now we are faced with the necessity of determining the toxic doses characterizing the medium and severe degrees of injury. We may determine the threshold values of the toxic doses, based on the hypothesis of the determination of injuries and on the consideration of the interval between the injurious and the lethal toxic doses, because these intervals may differ substantially if the toxic substances are different, according to this formula:

$$D_{ef(i)} = D_{ligh(0)} + \left(D_{lth(0)} - D_{ligh(0)}\right) \cdot r_i \qquad (10)$$

where $D_{ef(i)}$ - threshold values of the toxic dose for given outcome; $D_{ligh(0)}$ - toxic dose characterizing injury of light degree and which is determined according to formula 7; $D_{lth(0)}$ - lethal toxic dose, which is determined by formula 6; r_i - the injury coefficient.

We suggest using the following values of r_i — light degree of injury - $r = 0$; medium degree - $r = 0{,}3$; severe degree - $r = 0{,}6$; lethal dose - $r = 1{,}0$.

Thus, all the characteristics of the threshold values (fixed levels) of toxic injury during the action of poisonous substance are determined.

At last we have :

$$U_i = \frac{D_{abs}}{D_{ef(i)} \cdot \left(t_0 / t\right)^{n-1}} \qquad (11)$$

where t - time of exposure of the toxic substance.

The analysis of the given dependence for determining the complex fixed parameter of injury shows the necessity of more detailed study of the value D_{abs}. That's why the mechanism of determining this value according to dependence 3 suggested above (in general terms) must be concretized and then developed for receiving the possibility to calculate D_{abs} practically in reference to the zone of a chemical accident.

For this case we suggest using the following scheme of population injury ("absorption of toxic substance") to accidents involving hazardous substances, based on the data of a number of scientists.

As a result of destroying a tank a primary gas cloud is formed, and a big quantity of the toxic substance from the tank may go with this cloud. Simultaneously, the evaporation of spilled agent begins, and a secondary cloud is formed. Investigations show that the primary cloud as a rule has the higher concentration of the substance, but its influence on a "spot" object is limited in time (no more than 15-20 minutes).

The concentration in the secondary cloud is lower, but the time of its action may last from some hours to 24 hours and even more, depending on the substance and its quantity.

Thus, we may look at the following scheme of the toxic substance affecting the population during chemical disasters.

Conventionally we may divide the zone of toxic injury of the population into three areas. The primary and secondary clouds influence persons in the area S_1 . In the area S_2 only the secondary cloud influences the population, and only the primary cloud influences persons in the area S_3.

We have two variants of toxic injury objects in every area: the first has an area which is much less than the area of the injury zone (we shall call it a "spot" object) and the second has an area comparable to the area of the injury zone (we shall call it an "area" object).

Now we are going to determine the probability of toxic injury for a "spot" object. For this case we take the point M with the coordinates x and y as the prototype of the "spot" object. We are looking at the process of toxic injury at the point $M(x,y)$ accordingly in the areas S_1 , S_2 and S_3 .

During an elementary time interval dt at the point $M(x,y)$ a person will receive the following toxic dose:

$$dD = V \cdot q(t,x,y,O)dt$$

where V - the volume of pulmonary ventilation; $q(t,x,y,O)$ - the concentration at point $M(x,y)$ at the moment T.

The general absorbed toxic dose during the passing of the primary cloud over the point $M(x,y)$ is:

$$D_3 = V \cdot \int_{t_1}^{t_2} q(t,x,y,O)dt \qquad (12)$$

where t_1 -the time when the front edge of the cloud reaches the point $M(x,y)$; t_2 -the time when the back edge of the cloud reaches the point $M(x,y)$.

Now we determine the complex fixed parameter of toxic injury and the probability of injury to the population, based on dependencies 8 and 11 :

$$U_3 = \frac{D_3}{D_{ef(i)} \cdot \left(\frac{t_0}{t_2 - t_1}\right)^{n-1}}$$

$$F(U_{3i}) = 1 - exp\left[-(b_i \cdot U_{3i})^{\gamma_i}\right] \qquad (13)$$

So, considering the process of evaporation as a stationary process, the toxic dose at the point $M(x,y)$ from the influence of the secondary cloud in the area S_2 is:

$$D_2 = V \cdot q(x,y,O,) \cdot t \qquad (14)$$

where t - the time of evaporation of the poisonous substance or the time of staying of persons in the injury zone.

Correspondingly, the complex parameter of toxic injury and the probability of the injury are:

$$U_2 = \frac{D_2}{D_{ef(i)} \cdot \left(\frac{t_0}{t}\right)^{n-1}}$$

$$F(U_{2i}) = 1 - exp\left[-(b_i \cdot U_{2i})^{\gamma_i}\right] \qquad (15)$$

For calculation of the complex parameter of injury in the area S_1 we must take into consideration the imposition of injury action by both clouds, primary and secondary. It is suggested that ejection of the toxic substance at the moment of destruction of a tank (primary cloud generation) and its further spreading at the expense of the spilled agent (the secondary cloud) take place practically simultaneously. The probability of toxic injury from the primary and secondary clouds is described by the above-mentioned dependencies 13 and 15.

Looking at these dependencies, we may come to the conclusion that the second term in the right part of these equalities determines the probability of non-injury of the population. Thus, the probability that the population will not be injured during passing of the primary and secondary clouds is determined as:

$$P = \exp\left[-(b_i \cdot U_{1i})^{\gamma_i}\right] \cdot \exp\left[-(b_i \cdot U_{2i})^{\gamma_i}\right]$$
$$= \exp\left[-(b_i \cdot U_{1i})^{\gamma_i} - (b_i \cdot U_{2i})^{\gamma_i}\right]$$

Consequently, the probability of injury during the action of both clouds is determined as the dependence:

$$F(U_{1i}, U_{2i}) = 1 - exp\left[-(b_i \cdot U_{1i})^{\gamma_i} - (b_i \cdot U_{2i})^{\gamma_i}\right]$$

Now we will look at methodical approaches for determining the losses in population if the region of allocation of the people is commensurable with the area of the injury or if the region is larger than the injury area, i.e. if we speak about the "area" object.

Let us define an elementary area with dimensions $\Delta x \Delta y$ in the injury zone. The losses in this area are:

$$\Delta N_n = \rho dx dy - \rho \, exp\left[-(b_i \cdot U_i)^{\gamma_i}\right] dx dy$$

where ρ - the density of the population.

If we are going to add up all the losses in all the elementary areas inside the injury zone, increasing the number of the areas up to infinity and under the condition that their dimensions try to attain zero, a variable characterizing the general losses is expressed by the integral:

$$\Delta N_n = \rho \iint_S dx dy - \rho \iint_S exp\left[-(b_i \cdot U_i)^{\gamma_i}\right] dx dy$$

Taking into consideration that:

$$U_i(x,y) = \frac{D(x,y)}{D_{ef(i)} \cdot \left(\frac{t_0}{t}\right)^{n-1}}; \quad \rho \iint_S dx dy = N$$

We have :

$$N_n = N - \rho \iint_S exp\left\{-\left[b_i \cdot \frac{D(x,y)}{D_{ef(i)} \cdot \left(\frac{t_0}{t}\right)^{n-1}}\right]^{\gamma_i}\right\} dx dy$$

where N - the number of persons in the injury zone.

To calculate the integral we are going to use the theorem about the integral calculus mean value. Thus, the losses may be determined according to the dependence:

$$N_n = N - \rho S\, exp\left\{-\left[b_i \cdot \frac{\overline{D_S}}{D_{ef(i)} \cdot \left(\frac{t_0}{t}\right)^{n-1}}\right]^{\gamma_i}\right\}$$

where $\overline{D_S}$ - the mean integral toxic dose in the area S.

The mean integral toxic dose in the area S may be determined by integration, using the dependencies:

a) for the primary cloud:

$$\overline{D_S} = \frac{1}{S}\iint_S D(x,y)\mathrm{d}x\mathrm{d}y$$

where $D(x,y)$ - the toxic dose at the point $M(x,y)$, which is determined according to dependence 12;

b) for the secondary cloud:

$$\overline{D_S} = \frac{V \cdot t}{S}\iint_S q(\mathrm{x},\mathrm{y},\mathrm{O})\ \mathrm{d}x\mathrm{d}y$$

In order to determine the effective dose in the case of the primary cloud we must first determine the mean integral time of exposure.

Now we may use the dependence:

$$\overline{t}_S = \frac{1}{S}\iint_S t(x,y)\mathrm{d}x\mathrm{d}y$$

Thus, to determine losses in the area, we use the same dependencies as for the "spot" object, but we substitute values of the mean integral toxic dose $\overline{D_S}$ and the mean integral time of exposure $\overline{t}_S$ (for the primary cloud) instead of the toxic dose and the time of exposure at the point $M(x,y)$.

Table 1. The value of the parameters of distribution of Weibull

Parameters	Injury severity degree			
	light	medium	severe	death
γ	2.5	3.8	4.4	5.3
β_γ	0.889	0.904	0.912	0.92

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OIL SPILLS & AI: HOW TO MANAGE RESOURCES THROUGH SIMULATION

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ABSTRACT

Today, in the Mediterranean theater of the Upper Tyrrhenian, the ecological risk involving oil installations is still quite high. This is due to the fact that valuable environmental and tourist areas exist together with large industrial and port structures; in particular, recent events have demonstrated the danger involving oil spills along the Ligurian coastline. This study proposes an approach, to plan the operations that should be performed when accidents occur, based on the use of AI techniques.

INTRODUCTION

The release of polluting substances from ships is a particularly important phenomenon in the current Mediterranean configuration, in which modern tourist facilities are located close to oil terminals.

In this study, it is proposed to the use a combination of Fuzzy Logic and genetic Algorithms to create an Artificial Intelligence system designed to provide decision support when accidents occur (AI-DSS).

This system is designed to be integrated with an oil spill simulation model. Predictions about how the disaster may spread are developed by the simulation model and, by means of a time warp technique, the decision support tool plans the emergency operations.

The advantages of this approach are related to the fact that, by means of continuous re-calibration, the decision support tool corrects any erroneous estimates about the future behavior of the oil spill and about the possibility of using the requested resource in time.

The use of fuzzy logic to define the decision-related parameters (the possibility of moving barriers, etc.) when modelling exogenous variables (weather conditions, economic value of each area, etc.) makes the decision process easy to understand; on the other hand, the GAs are particularly efficient (considering the run time of the simulation developed) in "optimizing" medium-term planning. In fact, these choices depend on many different parameters and in particular on the development of variables affected by a high level of intrinsic uncertainty (due to the stochastic nature of the phenomenon).

The operating strategy is defined by regulating a set of independent exogenous variables (to minimize spreading, to protect strategic areas, etc.). The work presented also refers to a specific case to highlight the application potentials of this tool not only as an Emergency Manager DSS, but also as a means for defining the operating structures needed to handle this type of accident. In this case, it is proposed to use the DSS to recreate and evaluate the accident involving the Haven oil tanker (with a load of 140,000 tons of crude) in the port of Voltri on April 11, 1991 (an accident that put world famous Riviera tourist locations at great risk). The application of the theory of experiments is used to verify and validate the simulation model and to fine-tune the decision support tool. The accident considered emphasizes the need to reproduce special operational and complex procedures in the simulation model (towing the polluting source, containing rather than extinguishing the fire, etc.). To co-ordinate such complex procedures would be extremely difficult using the logic of traditional AI systems. However, working with combined techniques (hybrid AI systems) it is possible to generate good performances with limited development time.

THE REAL PROBLEM

The problem in question is very practical. One part consists in defining the correct disposition of the resources available in the area to guarantee that they can be used quickly. The other part involves help in managing such resources to limit the damage caused by these accidents. In the scenario considered, the operating resources include the equipment of the various public emergency forces and the apparatus of the companies which operate in the sector.

Since these are very costly tools and considering the fact that fortunately they are used only occasionally, their readiness level and deployment may be key factors in avoiding natural disasters. The system proposed, by using the DOE (Design of Experiments) theory, will identify the optimum configuration of the resources to utilize and will estimate the action time required by other structures located in contiguous areas. When a single

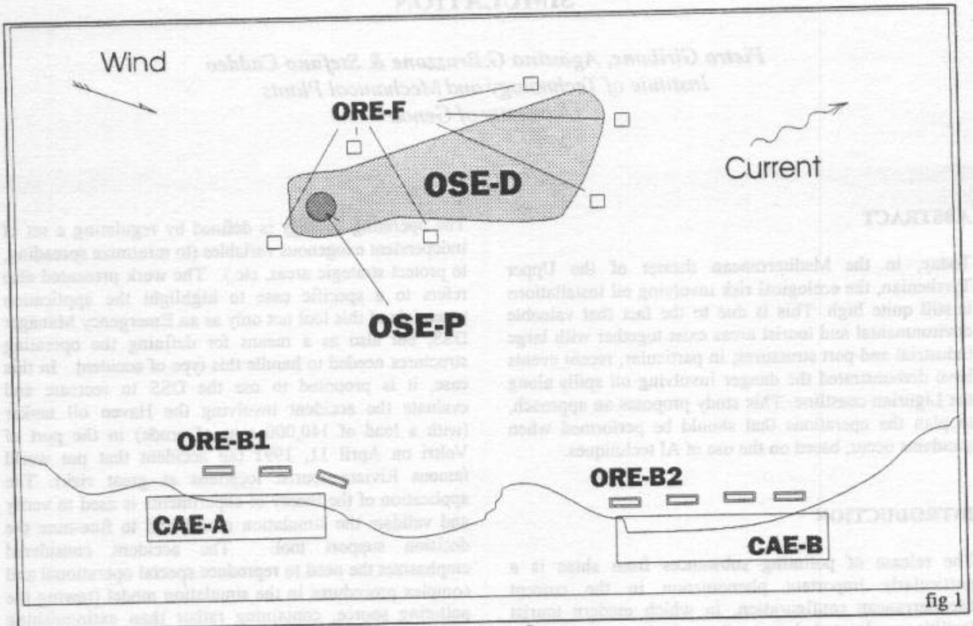

fig 1

crisis is being managed, and knowing the availability of resources, the system can propose a plan of action. Therefore, the organizational choices will be based on an in-depth analysis of the accident risk that can be obtained through the use of the simulation integrated with the DSS. In fact, from the data obtained, correct evaluations of the requirements can be extracted to reduce the risk to acceptable levels in a particular operating scenario. On the other hand, emergency planning refers to the tactical deployment of single units and the possibility of treating the spill with different methods. Thus, by using the simulator, it is possible to control the hypothetical future damage in real time in the areas close to the spill with variations in operating modalities.

MODELING THE SIMULATOR

To reproduce the behavior of the physical system being studied, a detail simulator was created to monitor and predict the behavior of the oil spill as well as its source. This simulation model was built in C++ and is very effective in terms of running speed.

The phenomenon in question is a function of aleatory variables of which at least the probability characteristics are known (type of distribution and statistical moments). The polluting sources may be defined with different modalities:

Source:

Stationary source

Mobile source

Polluting Phenomenon:

Floating spill

Crystallized sunken material

It is possible to characterize the compound released by defining its physical characteristics and resistance to different anti-polluting agents.

The simulation model must therefore use statistical distributions to extract the values simulated, using the Montecarlo technique, within the distributions introduced as input. Therefore, once these distribution are defined, it is very simple to perform a sensitivity analysis using replicated runs.

Based on the particular conformation of the bottom and typical sea currents in the area, the simulator proposed can extend the available measurements to the entire area of the sea affected by the phenomenon. The method used extends the validity of the single measurements to the entire grid being examined through the use of continuity equations. In this way, even starting with a few measurements, it is possible to obtain a comprehensive analysis of the intensity of the sea and the current in each point. The computer must be used for a certain period of time (about ten minutes on a personal computer for the equivalent of the exogenous data necessary for 12 hours of simulated time) to perform such a diffusion of the exogenous variables over the entire grid of the map being studied. However, the data calculated in this manner can be re-used until new information becomes available and also for different simulations performed over the same time period (e.g.: replications, time warp).

This simulator was equipped with a graphic interface that can be used to quickly interpret the results obtained and to validate the model at a graphic level (fig. 1).

Once this first phase was completed, the uncertainty on the final values was calculated using replicated runs.

The experimental error of the model, due to the intrinsic stochasticity of the phenomenon, was estimated with the MSpe time analysis technique developed by this research group. Thus, not only was it possible to identify the confidence band of the model, but also the minimum run time of the simulator required to obtain congruent results. In our case, for the scenario hypotheses that we developed, this time interval was less than 6 simulated hours (less than one minute of real time).

Obviously, there is a correlation between the amplitude of the stochastic input variables and the amplitude of the confidence band on the final results.

However, without being able to generalize, it can be experimentally checked that the Mean Square pure Error has an almost uniform development for percentage variations of the wind and current parameters of around 5%. (fig. 2) For this reason, it was decided to consider this maximum amplitude segment as the reference value on the significance of the results for each case in which the input variables were affected by an uncertainty that was less than the threshold value. Otherwise, it is obvious that the tests must be repeated under those particular initial conditions to obtain an efficient estimate of the system.

THE FUZZY SETS USED

Fuzzy variables were used within the decision support process to check the management of the anti-pollution equipment. The logic system refers to the following base objects:

OSE	Oil Spill Entity
ORE	Operational Resource Entity
CAE	Coastal Area Entity

These variables basically have a dual structure:

Endogenous:
Resistance to different chemical agents (OS)
Time necessary to contaminate a certain area (OSE->CAE)
Danger Level (OSE) etc.

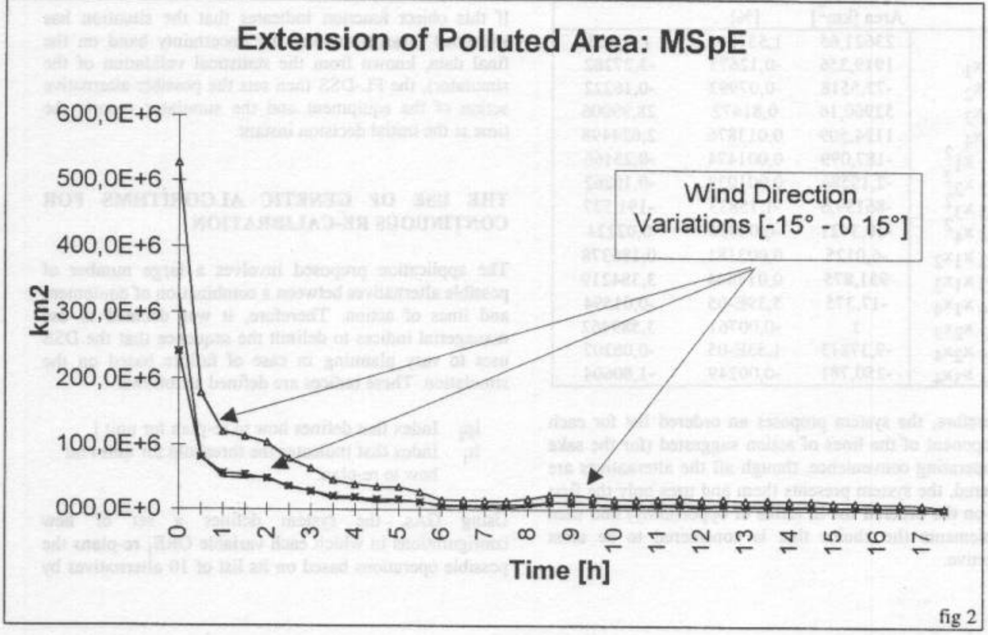

fig 2

Exogenous:
- Sea Conditions
- Wind Conditions etc.

Operating
- Spill intervention time (ORE->OSE)
- Intervention time on an area to prepare protection devices (ORE->CAE)
- Effectiveness of the possible intervention (ORE->OSE) etc.

General Strategy Decision Supports
- Priority of the areas with enhanced value
- Priority of the coastal areas
- Intervention objective (medium, short or long-term) etc.

The membership functions shown in figure 3 (-L, -M, -S, +S, +M, +L) were theorized for each fuzzy variable. The combination of this data, using fuzzy rules, determines the opportunity to take action on each possible target for each ORE (OSE or CAE depending on the type of operating equipment).

Table I : Regression Coefficients

	Y1: Extension of The Polluted Area [km^2]	Y2: Value of The Damage Tourist Area [%]	Y3: Duration of the Operations [h]
b_0	23621,65	1,557665	137,165
$b_1 x_1$	1919,356	-0,12673	-3,27282
$b_2 x_2$	-72,5518	-0,07992	-0,16222
$b_3 x_3$	52960,16	0,81472	28,99006
$b_4 x_4$	1124,509	0,013876	2,624498
$b_{11} x_1^2$	-187,099	0,001474	-0,25166
$b_{22} x_2^2$	-2,19586	0,001033	-0,10262
$b_{33} x_3^2$	-86139,6	-1,15833	-191,527
$b_{44} x_4^2$	-10,3421	-0,00026	0,02224
$b_{12} x_1 x_2$	-6,0125	0,003181	0,186378
$b_{13} x_1 x_3$	951,875	0,017844	3,384219
$b_{14} x_1 x_4$	-17,375	5,39E-05	-0,01594
$b_{23} x_2 x_3$	1	-0,00761	3,589462
$b_{24} x_2 x_4$	-9,37813	1,53E-05	-0,08207
$b_{34} x_3 x_4$	-250,781	-0,00249	-1,80604

Therefore, the system proposes an ordered list for each component of the lines of action suggested (for the sake of operating convenience, though all the alternatives are ordered, the system presents them and uses only the first ten on the ordered list in terms of opportunity) and then implements the choice that is considered to be most effective.

Table II: Statistical Test on Regression

	Sum Square	DoF	Mean Square	F0	$F(0.05,v_1,v_2)$
Y1: Extension of The Polluted Area [km^2]					
Regression	465E6	14	33.236E6	28,899	>2,48
Error	16.1E6	14	1150084		ok
L.O.F.	10.2E6	10	1024733	0,7002	<5,96
Pure Error	5.85E6	4	1463463		ok
Y2: Value of The Damage Tourist Area[%]					
Regression	1,3813	14	0,098667	265,02	>2,48
Error	0,0052	14	0,000372		ok
L.O.F.	0,0048	10	0,000480	4,7054	<5,96
Pure Error	0,0004	4	0,000102		ok
Y3: Duration of the Operations [h]					
Regression	7687	14	549,098	21,511	>2,48
Error	357,3	14	25,52522		ok
L.O.F.	325,5	10	32,55485	4,0943	<5,96
Pure Error	31,80	4	7,951153		ok

INTEGRATION WITH THE SIMULATOR

Once the fuzzy support module (FL-DSS) has supplied the data relative to each single operating procedure, the simulator makes a projection in this hypothesis with a duration equal to the period suggested by the FL-DSS.
At this point, the system calculates the contamination spread level and then compares it with the same variable at the initial time instant.
If this object function indicates that the situation has worsened (also evaluating the uncertainty band on the final data, known from the statistical validation of the simulator), the FL-DSS then sets the possible alternative action of the equipment and the simulator reports the time at the initial decision instant.

THE USE OF GENETIC ALGORITHMS FOR CONTINUOUS RE-CALIBRATION

The application proposed involves a large number of possible alternatives between a combination of equipment and lines of action. Therefore, it was decided to use managerial indices to delimit the sequence that the DSS uses to vary planning in case of failure based on the simulation. These indices are defined as follows.

Ip_i	Index that defines how to re-plan for unit i
It_i	Index that indicates the threshold for unit i on how to re-plan.

Using GAs, the system defines a set of new configurations in which each variable ORE_i re-plans the possible operations based on its list of 10 alternatives by means of two indices, choosing the j-th alternative as determined by the formula:

$$j = (int)(Ip_j/It_j)$$

Based on the level of pollution produced after the reference dt, the system orders the results of the initial set and recombines them using the GAs to obtain a new set. This operation is managed by the module called GA-DSS.

This procedure is repeated until the "normalized corrected" diameter of the search area involved delimited by the points of the n-th set is less than a predetermined percentage of the analysis range. This diameter is calculated with the formula:

$$Dc=\max(K_1) \qquad K_1 = K - K_0$$

$K_0 =$ {Set consisting of the first ten percent of the ordered elements of K}

$K =$ {Ordered set of the distance of Pi from Pj for each i j}

In this theoretical case, reference is made to availability that can be concentrated in about 30 different resources (for which the GA-DSS operates on 60 independent variables) and continues until the range delimited by the points obtained is equal to 5% of the initial analysis range (thus, it is possible to limit the optimum solution with a number of very reduced iterations). Once this phase has been completed, the best configuration is used as a new decision support configuration based on the value of the object function from among those proposed in the set of final points.

AN APPLICATION EXAMPLE

The disaster to be reproduced involves the Haven in the oil terminal of Genoa Pegli on April 11, 1991. At that time, due to accidental causes, a fire broke out on board the ship (140,000 tons of crude oil).

During the operations performed immediately following the outbreak, assistance vessels and support equipment were transferred from nearby areas (the Adriatic coast, the Côte d'Azur) to limit the phenomena and it was decided to tow the burning ship without extinguishing the fire in order to consume as much oil as possible through combustion.

Once the towing operation was completed and the floating barriers were prepared on the coast, the ship was sunk in an area with a shallow bottom. This was decided to make it easier to carry out the anti-pollution clean-up operations that were performed afterwards using professional divers and volunteers.

Using the proposed decision support model (AI-DDS),

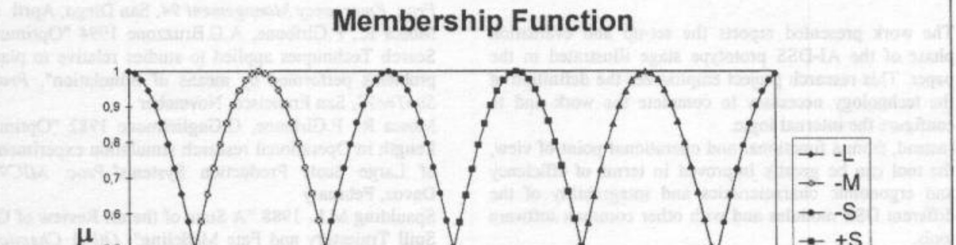

fig 3

the case in question was re-analyzed introducing a ship "in flames" as the source with a low percentage probability of sinking and with the stored oil data relative to the case.

In this situation, and starting from the initial conditions, the experiment was performed with a controlled procedure by the AI-DSS.

Several simulations were performed with reference to different scenarios relative to the following Input variables.

- Number of available extendible barriers
- Number of units which can filter.
- Percentage of the support equipment located outside the area.
- Average intervention time of the support equipment outside the area.

The following variables were controlled as output:

- Extension of the polluted area
- Value of the damaged tourist area
- Duration of the operations

The results obtained by creating a base-2 central composite design led to the identification of the most significant parameters for each variable. Thus, by constructing the polynomial meta-models (table 1), it was possible to determine the initial resources necessary to handle this type of crisis in the "best" way; table 2 reports the final numerical results.

CONCLUSIONS

The work presented reports the set-up and evaluation phase of the AI-DSS prototype stage illustrated in the paper. This research project emphasizes the definition of the technology necessary to complete the work and to configure the internal logic.

Instead, from a functional and operational point of view, the tool can be greatly improved in terms of efficiency and ergonomic characteristics and integrability of the different DSS modules and with other common software tools.

In fact, this work group will focus future efforts on developing an efficient shell equipped with convenient color maps to make it easier for the operator to check the operating logic and also to fine-tune the AI-DSS until it can also be used to plan low-level operations.

This type of tool inevitably will be used as a base element to build training equipment that can be used as a support to train the personnel who will manage this type of accident. In fact, by integrating this tool with an effective interactive graphic interface, planners can handle hypothetical scenarios and at the same time review and re-plan the operation by referring to accidents which have already occurred. In this way it is possible to incorporate the DSS fine-tuning phase with the specific training of managers who handle these emergencies and in efficiently using a decision support tool like the one proposed.

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INTELLIGENT DECISION SUPPORT FOR COOPERATING EMERGENCY MANAGERS: THE TOGA BASED CONCEPTUALIZATION FRAMEWORK

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ABSTRACT

The paper presents the results of a preliminary study related to the conceptual design of an Intelligent Decision Support System (IDSS) for cooperating emergency managers. Authors postulate to shift the designer efforts from passive DSSs, based on so called *menu-driven paradigm*, to the active DSSs based on the *goal-driven paradigm*. IDSS kernel should be the user-friendly interface between classical DSS and emergency managers. The general conceptualization methodology employed in this work is TOGA (Top-down Object-based Goal-oriented approach). The suggested architecture of IDSS is based on the model of Abstract Intelligent Agent, complemented with the results of the CEC funded Projects ISEM[1] and MUSTER[2].

INTRODUCTION AND MOTIVATIONS

In the stormy developing postindustrial society, environmental, technological and social decisions involve ever more risk and their consequences are often hardly predictable. This situation results from the continuously increasing decisional domains, their complexity, and many other factors of post-modern society. Very sophisticated, fast and precise modern technology requires qualitatively new tools for its control. Numerous disasters, caused by natural events and human-errors require an emergency and recovery management which need large volumes of data. For singular emergency managers, as well as, for the cooperating staffs, ever more frequently, these data are hardly evaluable and applicable. On the other hand, human mental capabilities are not yet in adequate way supported by new computer technologies which could significatively diminish probability of serious managerial errors.

So called passive Decision Support Systems (p-DSS) have been the first attempt to the computer aid for emergency managers. Unfortunately, their application requires from their users continuous learning and training to which typical emergency managers are not enough motivated. The use of large p-DSS involves so much technical decisions that these systems either require continuous effort of computer specialists or they are not used in practice.

Passive DSS is based on available "conventional" elements, methods and data-base management technologies. In these systems large part of the user decisions relies on the choice of the concrete button from a menubars or menutools being parts of a visualized hierarchical menu structures. In this way we can say that their input/output interfaces are funded on the *menu-driven paradigm*.

Let us mention that many decisions which are intuitively easy recognized by the managers as not "key decisions" or "less important " require only formal well structured knowledge (for example, searching in data bases, optimization), and should be recognize and allocated to DSSs. As the consequence, ever more frequently, *classical passive DSSs based on the menu-driven paradigm do not satisfy the requirements of their users.*

The contrary to menu-driven paradigm can be *goal-driven paradigm* of decision support. In this case, a computer system should be some kind of an active cooperator of its user, what we see, for example in (Hawgood et al. 1992) and (Muhanna 1993). Application of goal-driven paradigm eliminates redundancy of not actual in this moment alternatives and suggests choices determined by criteria defined on higher abstraction levels, for example related to importance, risk, duty or to a consequence of previous choices. In order to make autonomous decisions the Decision Support System needs a certain model of decisional processes (Yager 1992), (Watabe et al. 1992), (Michalski 1992) adaptable to particular choices resulting from a generic emergency scenario, and which are consequence of the current situation of emergency. In such context, IDSSs (Intelligent Decision Support System) can be viewed as computerized interfaces for "fitting" passive DSS functions to the requirements and preferences of man.

In general, IDSS are especially important when:

(a) the amount of information necessary for the management is so large, or its time density is so high, that the probability of human errors during emergency decision-making is not negligible,

(b) the coping with unexpected situations requires from the managers the remembering, mental elaboration and immediate application of complex professional knowledge, which if not properly used causes faulty decisions.

The basic problems for design and development of IDSSs are the conceptualization and representation of the user knowledge. Recent research results (Kay 1991), (Beaumont 1994) lead to the conclusion, that modeling of the user roles is required for identification and specification of this knowledge.

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[1] ISEM (Information Technology Support for Emergency Management) ESPRIT Project no. 2322.

[2] MUSTER (Multi-User System for Training and Evaluating Environmental Emergency Response) CEC ENVIRONMENT Project.

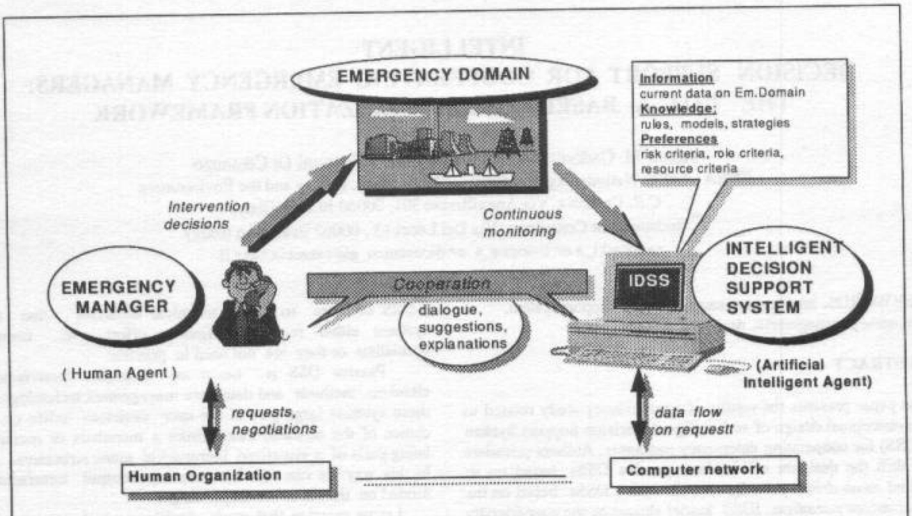

Fig. 1 General idea of an Intelligent Decision Support System for emergency management

We assume (Gadomski et al. 1993), (Balducelli et al. 1993) that user models should be based on a more general model of an intelligent agent which is able to realize autonomously goal-driven interventions in its environment.

Therefore the *goal-driven paradigm* must be based on a generic ideal model of decision-maker and on its decomposability on human and computer decision-makers. For such task *a general model of abstract intelligent agent as a role-dependent decision-maker is necessary.*

We say abstract, because such model of intelligent agent should be independent on its application-domain and independent on its software implementation environment.

The design of IDSS for EM (Emergency Management) requires an integrated application of the models and methodologies related to :

- large-scale emergency management
- abstract intelligent agent architecture
- decision-making under multilevel risk conditions and based on uncompleted and uncertain information or knowledge
- cooperation between intelligent agents
- computer aided training.

Formal specification frames of the behavior and knowledge of an ideal emergency manager (e-m) are the indispensable tools for IDSS design. This meta-knowledge is necessary for:

- acquisition of the domain-dependent knowledge (about EM)
- elaboration of the scenario of e-m activity
- allocation of the e-m activities and knowledge to IDSS
- definition of the new man-machine interface functions,
- standardization of the design documentation.

The aim of this paper is to indicate some criteria for the development and design of IDSS for EM. It should be a personal support for emergency managers working in frame of a large-scale emergency management system. Here, large-scale emergency-management concerns big industrial centers, nuclear or chemical plants, ports, railways networks, airports, as well as regional or national emergency organizations. A general view of the idea of IDSS is illustrated in Fig. 1.

CONCEPTUAL FRAMEWORK : ELEMENTS OF TOGA

In the recent years the models of intelligent agents are strongly investigated (see the subject matter literature, for example (Michalski 1992), (Hanks et al. 1993), (Gadomski 1994a), (Gadomski 1994b). Different new approaches to the software agents, like a general idea of agents-oriented programming (Shoham 1993), interactions of softbots (taskbots, userbots - the suffix "bot" is used for "software robot" (Com. ACM 1994) and others, have been analyzed. In this context we argue a domain-independent conceptualization of agent architecture which is based on Top-down Object-based Goal-oriented Approach (TOGA). The TOGA methodological part was inspired by Michalski, Stepp, Dontas, and Collins papers (Michalski 1983), (Stepp 1986), (Dontas 1988) and (Collins 1989), . They have proposed a main idea of the connection of an *object-based* conceptualization with *goal oriented* approach. In the plausible reasoning patterns they introduced too a reasoning generalization hierarchy. The conceptualization of artificial physical systems is an integration of Lind's (Lind 1982) MFM (Multi-level Flow Modeling) framework with, generally known in physics and engineering, processual representation of the physical phenomena. The *top-*

down approach is a generalization of the basic concepts of the structural design .

The TOGA approach being developed by Gadomski, was initially investigated in ENEA in the frame of the ISEM Project (Gadomski 1989) and, theoretically and practically analyzed in the fields of robotics and operator support systems (Gadomski 1993), (Gadomski 1994a.) Recently, the experiences acquired with the use of AIA to the modeling of emergency actors during collaborative training (Balducelli 1994) was also presented on the First and Second International Round-tables on AIA (1993, 1994).

According to the TOGA assumptions *we are able to define general architecture of AIA and basic functional schema of the domain-independent decision-making engine.*

TOGA is also a meta-tool for knowledge-based system development and can be partially confronted with the KADS methodology (Schreiber et al. 1993).,

Here only some selected information about TOGA are presented. The TOGA theory is composed of three elements:

1. Theory of Abstract Objects (TAO), which is a domain independent conceptualization system;
2. Knowledge Conceptualization System (KNOCS), which includes the axiomatic assumptions and definitions related to: conceptualization of the real world, physical realization of an abstract intelligent agent and the domains of its goal-oriented activity;
3. Methodological Rules System (MRUS) for specification of complex problems.

Fig. 2 presents the structure of the TOGA conceptualization layers.

TAO: Theory of Abstract Objects

Any theory can be considered as a frames system which enables structuring and operation over a certain class of sets. In the case of the Theory of Abstract Objects (TAO) its domain may be any numerable set Z, its elements are called *primitives* (or *vocabulary*). TAO is a frames system which enables structuring the primitives into the forms of:

- *objects;* specified by *object names*, *attributes' names*, *values*, and *value domains*.

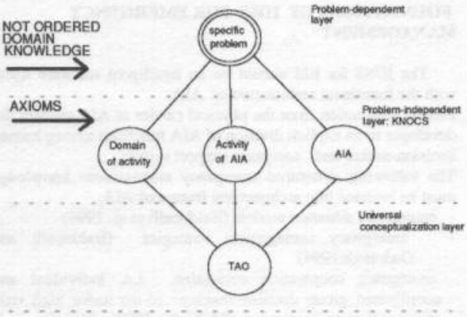

Fig.2 Three layers of the TOGA conceptualization

- *relations*; linking the objects attributes, and enabling the creation of isolated networks of objects
- *world-of-objects* (w-o-o); relational isolated networks of objects, and can be:
  - * arbitrarily divided into systems and their environments,
  - * aggregated in *universes of objects*.

TAO includes the definition of the class of singular objects called *agents*, and the formalization of the concept of the *point-of-view* referred to an object. The agents are particular objects which *are able* to create or to modify other objects inside their world-of-objects, i.e. this activity is not uniquely determined by the state of these w-o-o. They can be treated as "normal" objects in another word of objects. From designers perspective, TAO can be considered as a conceptual interface between KNOCS and programming languages.

KNOCS: Knowledge Conceptualization System

The Knowledge Conceptualization System (KNOCS) is a system of axioms and definitions for the description and conceptualization of the real world from the perspective of a real AIA.

KNOCS assumes that every product of human reasoning activity can be conceptualized in the framework of TAO. After TAO, KNOCS is a second conceptualization layer. It contains three fundamental frameworks of :

- *goal-oriented activity* of AIA , - *domain of activity* (d-o-a) of AIA, - AIA model.

All of them consist one terminological system. In this way, KNOCS enables conceptualization of different real-world systems such as industrial plants, robots, human operators or organizations. It also has the role of a conceptual interface between the designers and domain experts.

MRUS: Methodological Rules System

In the perspective of designers, the Methodological RUles System (MRUS) is a methodological approach to the top-down knowledge ordering for the specification of complex problems. It assumes that, at the beginning of a problem specification, the knowledge of the problem solving agent is incomplete and not goal-ordered. The problem specification activity is based on two fundamental mechanisms:

- top-down mechanism: it indicates the specification direction: from very general statements on the top abstraction levels to the details which are the elements of the particular problem solution;
- goal-driven mechanism; it always controls the links between the specified/identified object and the problem goal.

This mechanism creates bottom-up rules (synthesis rules). The rules of the MRUS system concern the meta-preferences criteria of AIA, independent on abstraction levels of problem specifications, they also enable "navigation" into the KNOCS frameworks.

Framework of Abstract Intelligent Agent

In frame of KNOCS, a general architecture and basic reasoning mechanism of simple and intelligent abstract agents, are defined. The construction of these agents if funded on the following basic concepts:

information: how situation looks (before, now, in the future)?
knowledge: how situation may be classified, and what is possible to do ?
preferences: what is more important ?
goal: what should be achieved ?

More precisely, these relative concepts always refer to a predefined d-o-a which is a source of information *(inf)*. They are defined together by the following two generic reasoning processes executed by the *preferences system (PR)* and *knowledge systems (KN)*:

$$goal = PR\ (\,inf1)$$
$$inf3\ = KN[goal]\ (\,inf2)$$

where *inf-i* may be any element of the current abstract domain of activity. Abstract d-o-a can be a representation of the real d-o-a of a physical agent. In this way, *PR* produces a goal, the goal activates an adequate *KN* which produces a new information. The carrier of these processes is called *abstract simple agent* (ASA). Its architecture is defined as a triangle composed of : abstract d-o-a, preferences system, and knowledge system.

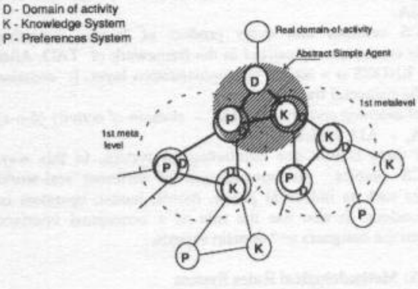

Fig.3 TOGA framework of AIA (Abstract Intelligent Agent) functional. architecture.

Let us now introduce a definition of Abstract Intelligent Agent: *AIA is an abstract agent which is able to reason about, and modify its own knowledge and preferences.*

In TOGA, AIA consists of the hierarchical pyramidal structure of ASAs. For the modifications of KN and *PR* of the basic ASA, these two systems must became abstract domains of activity for two ASAs located on the higher *meta-level*. Every next meta-level includes more ASAs. This structure is illustrated in Fig. 3.

In this way , for example, the basic conceptualization of a learning process is represented as:

$$inf\,3(KN_1) = KN_2\ [goal_2]\ \ inf2(\,KN_1)$$

where KN_n is a n-th meta-knowledge,
$inf\text{-}i\,(Da_n)$ is a i-th information from the abstract d-o-a Da_n.
$goal_2$ is a goal created on the 2nd meta-level of AIA.

Decision-Making Engine, DME

Every decision-making relating to a selected Da_n requires knowledge and preferences on a higher meta-level of the AIA architecture. According to TOGA this process is defined as follows:

Decision-making (d-m) is a mental activity implied by the possibility of choice, started when either choice criteria are unknown, or alternatives are unknown, and finished when the choice is performed.

Decision is a result of this choice and refers to the state of currently analyzed domain-of-activity: This domain can be a knowledge or preferences on the AIA different meta-levels.

We should mention that choice criteria are elements of the preferences system - PR_{n+1} , and the alternatives are included in the knowledge system - KN_{n+1}. As consequence, DME must work on the *(n+2)* meta-level.

For the reason of universal, i.e. level-independent , role of DME, it has to have an ability to the activation of various problem-dependent searching, learning or optimization procedures. Methods applied used into these procedures depend on the particular properties of decisional problems.

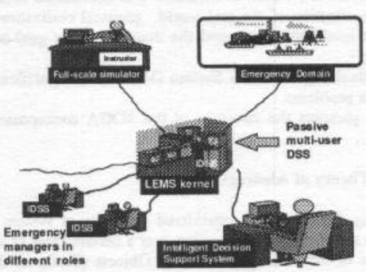

Fig. 4 Large-scale Emergency-Management System, LEMS

FOUNDATIONS OF IDSS FOR EMERGENCY MANAGEMENT

The IDSS for EM should be an intelligent software agent with the functional architecture of AIA.

Formal abstraction from the physical carrier of AIA enables the developer to an explicit division of AIA functions among human decision-maker and computer support system.

The following structured emergency management knowledge must be inserted into architectural frames of AIA:

- emergency situation models (Balducelli et al. 1994)
- emergency management strategies (Balducelli and Gadomski1994)
- emergency cooperation constrains, i.e. individual and coordinated group decision-making (d-m) under high risk, stress and time constrains (Muhanna 1993), (Watabe et al. 1992).

The above knowledge has been partially elaborated in frames of the ISEM, MUSTER and CAMS (Fantoni et al. 1994) projects.

As it is shown in Fig. 4, the main design assumption is to separate passive components of LEMS from the active personal DSS , i.e. Data Bases from Knowledge Bases.

According to TOGA, the problem of IDSS development should be divided on the following conceptual tasks:

1. Choice of a real application domain.
2. Definitions of the basic terminology and criteria for a description of the generic EM in frame of an Emergency Management Conceptualization System.
3. Top-down identification of the Generic Scenario of Emergency Management (GSEM); in terms of previously defined terminology, such as agents, actions, decisions, and domains of activity.
4. Decomposition of GSEM on model-based functions of emergency manager, and models building (every agent activity is an activation of its functions).
5. Definition of general architecture of LEMS reusing the elements of the available p-DSSs.
6. Specification of IDSS kernel architecture and its conceptual design by the choice and application of adequate software tools and methods
7. Validation of the received conceptual products.
8. Implementation of the prototype.
9. Verification and testing of the kernel with an external emergency domain simulator.

In this way, the IDSS can be realized in the open-system architecture using flexible incremental prototyping approach. Hypothetical functional structure of the IDSS is illustrated in Fig.5.

Emergency Management Conceptualization System

The experiences from the ISEM and MUSTER projects indicates that one of the basic problems of the conceptual design of decision support systems for large scale emergency management is the lack of uniform and complete conceptual web, especially on the level of generic emergency-management scenario.

Reconceptualization and unification and of the multi-disciplinary terminology and elimination of terminological redundancy in the domain of EM is indispensable task in the IDSS development. It is necessary:

- for reusing of the elements of p-DSSs ,
- for standardization of the methodology for the user-tailored domain-dependent knowledge acquisition,
- for formal verification of the completeness and congruency of the used models.

Therefore the elaboration of an Emergency Management COnceptualization System (EMCOS) with a Language (EMCOL) are here urgent tasks for knowledge engineers .

Generic Scenario of Emergency Management (GSEM)

GSEM is a network of the domain-independent activities of the manager. These activities should be modeled and linked with the implemented modules of LEMS and with specified activities of the user. GSEM must be abstracted from specific emergency domains but under constrains of human organization activities such as: cooperation, coordination and , in general, multi-agent decision-making.

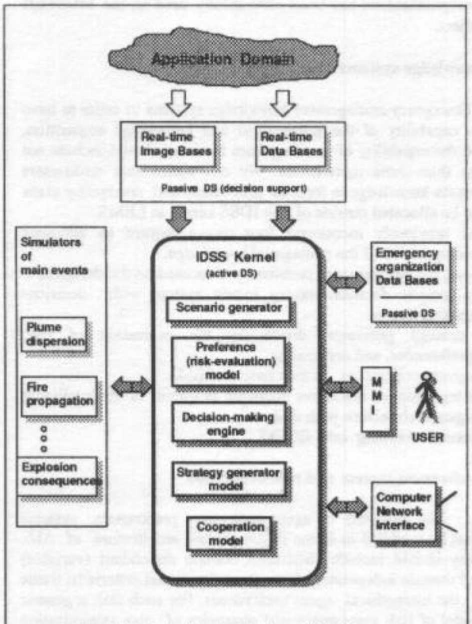

Fig. 5 Main functional modules of LEMS system.

Four basic domains of activity of emergency-agents are distinguished:

D1 - *intervention domain*; it is an abstract emergency domain and the end-domain of the manager decisions,

D2 - *data-bases domain;* it is a domain of periodically updated information, knowledge and duties. It includes logistic data, such as DBs on emergency organizations, on intervention resources, and on emergency plan and emergency procedures.

D3 - *event simulation domain*; it is a source of "what if" data about possible futures consequences of the current state of emergency and about planned interventions

D4 - *cooperation domain*; it is a dynamic domain consists of cooperating agents. It is a sources of messages necessary for the emergency manager reasoning and his decision-making activity. In general, a consensus on the communication subjects between cooperation agents must be achieved.

Real and Abstract Domains of Activity

The physical emergency domain is a domain of the goal of emergency management activities. A mental image of this domain is the direct domain of activity of the manager, there he expects to achieve particular intervention-goals. The suggested LRS conceptualization framework is described in the paper (Balducelli 1994). It is composed of three layers :

Layout layer (LL), Resources Layer (RL), Scenario Layer (SL). The SL and RL layers are mapped into LL. All of them are represented by abstract objects-relations networks. This conceptualization has been successfully used in the MUSTER Project.

Knowledge systems

Emergency-management knowledge systems in order to have the capability of the information and knowledge acquisition, and the capability of learning from the user, should include not less than three meta-levels. We can notice that multi-users domain-knowledge in form of procedures and emergency plans can be allocated outside of the IDSS kernel in LEMS.

The previously mentioned four ds-o-a require an adequate decomposition of the managerial knowledge.

Here, the key research problems are focused on the design of:
- a generic decision-making expert system with decision-making engine
- strategy generator, driven by the evaluation of risk, preferences, and constraints
- agents cooperation, in the context of EM.
- integration of the above elements in frames of the intelligent agent architecture with their
- formal mapping into GSEM.

Preferences system and risk evaluation

The hierarchy of agent emergency preferences systems must be modeled in frame of the generic architecture of AIA. They should include structured domain dependent (variable) and domain independent (invariant) decisional criteria in frame of the hierarchical agent preferences. For such task a generic model of risk assessment and strategies of risk minimization are necessary. The preferences related to risk evaluation play fundamental role in AIA reasoning processes, therefore a generic model of hazard and risk is under elaboration in frame of the TOGA frameworks.

The preferences of a particular emergency manager are role dependent but, in general, can be represented as duties, situation-dependent instructions, and moral rules/constrains. They are decomposed relatively to the basic D1-D4 activity domains, and depend on the range of managers responsibility, competencies, and assigned tasks.

Summarizing, the decision-making processes require risks and benefits evaluation in two basic contexts: direct intervention domain (emergency-domain) and communication domain. The last one concerns the same and higher level managers. For example, one of the top preferences is the request of autonomous intervention in situation of the loosing of communication link between cooperating managers.

A time-scale preferences should handle the real agent actions according to the time-constraints of the user possibilities and the dynamics of emergency domain.

The Fig. 6. illustrates a localization of main elements of the EM functional modules into the AIA structural framework.

CONCLUSIONS

This paper, according to the goal-driven paradigm, indicates only some main problems and criteria of the development of IDSS for emergency managers. Today, IDSS seems to be realistic and attractive task for interdisciplinary teams of specialists.

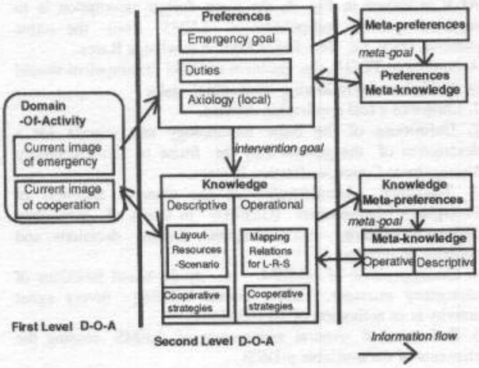

Fig. 6 An example of basic architecture of abstract emergency manager

We can notice that the application of the TOGA methodology and the suggested IDSS architecture are not only independent of specific emergency domains but they also are independent of the concrete size of the implemented data-bases, knowledge and preferences. This property should facilitate the development of personal IDSSs in the incremental prototyping manner. The personal IDSS can be expanded according to the local specific possibilities and needs. It can qualitatively support different Large-scale Emergency-Management Systems, especially where computerized information systems are just in use.

IDSS should have the capability of an explanation of its own support decisions, suggested intervention decisions, as well as a capability of evaluation of its user decisions.

From the technical point of view, the IDSS kernel should be interfaced with:
- data bases and knowledge bases containing object-based representation of the emergency physical domain (models of resources, risk objects and events), plans and procedures, all of them may be a part of conventional passive information system.
- a GIS systems for the presentation of pictorial visualizations of dynamic emergency scenarios (using maps).
- man-computer interface equipped with a set of multimedia tools allowing visualization of the real events and resources, using pictures and video-sequences.
- external simulators to simulate propagation of emergency events, such as: plume, fire, heat, etc.

In general, IDSS can be also seen as a set of expert systems hierarchically structured according to the TOGA frameworks. Partial models of the reality, everyone representing a certain single-user role-dependent viewpoint should be included.

As a final remark, we can notice that the decomposition of the role of ideal emergency manager on the roles of human user and IDSS, and continuous development of ever more detailed models of emergency management will shift human decisions on higher preferences levels, which include evaluation of the credibility of data, the application of moral and cultural criteria, as well as new consensus criteria for cooperative work.

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DESIGNING AN OIL SPILL INFORMATION MANAGEMENT SYSTEM

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ABSTRACT

This paper presents the architectural design of OSIMS, an Oil Spill Information Management System, which is an integrated information management tool that consists of an object-relational database management system, an adaptive decision suport sustem, an advanced visualization system (AVS) and a geographic information system (GIS). OSIMS will handle large and diverse databases of environmental, ecological, geographical, engineering, and regulatory information and will be used for risk analysis and contingency planning.

INTRODUCTION

Successful response to oil spills requires marshaling critical information in a real time (often for a sustained period of days-to-weeks) over a wide spectrum of topics, including surveillance data, environmental conditions, ecological factors, and countermeasure options (both from a technological and a legal perspective) (Meyers *et al. 1989*).

Response operations have many facets that are often fulfilled by a variety of agencies, all of which need access to critical information. A high degree of organization and preparation is required to support these information needs effectively (Jensen and Tebeau 1991).

Some of the information (e.g. geographical, ecological, legal, containment, and clean-up equipage, environmental sensor locations) can be acquired and organized in advance, typically through a Geographical Information System (GIS). Other types of information (e.g. winds, waves, and currents; vessel traffic; fishing fleet operations) must be dealt with in real-time. Tactical/operational decision-makers need to have this vast variety of data accessible, generally in a graphical display form. They also need to have comprehensive data pertaining to the oil spill event for the duration of the crisis and beyond. Obviously, a computer-based information management system is essential.

Similarly, there is a need for an organized information management system to support strategic activities, e.g. planning, training, and event reconstruction. The same basic information system should be able to support both tactical and strategic needs (Harrald *et al.* 1990).

This paper presents the architectural design of OSIMS, an Oil Spill Information Management System, which is an integrated information management tool based on an object-oriented database design that may provide comprehensive data pertaining to an oil spill event for the duration of a crisis.

In the following section, we present the database management system, that is developed to handle large and diverse databases of environmental, ecological, geographical, engineering, and regulatory information. GISs and Advanced Visualization techniques (AVS) to be used to integrate a variety of databases for risk analysis and contingency planning are presented afterwards. Finally, we present an adaptive decision support system which is designed to support oil-spill response decision makers with automated expert systems and tools to assist in strategic, tactical, and operational decision-making.

DATABASE MANAGEMENT SYSTEM

In preparation for an oil spill event scientists must deal with huge volumes and diverse sets of data. The proposed database will serve as an integrated data repository to many other types of subsystems. Decision support systems, visualization, and geographic information systems will access the data stored in the database. The database management system will provide transaction management for concurrent access, security control, and ad-hoc queries based on attributes and contents of pertinent datasets.

These data include geographic and environmental data, time sequenced observational data from cruises, buoys, shore stations, satellite images, and gridded multi-dimensional data from various simulation models. Regulatory information must also be stored and manipulated in a seemless manner. Most of these data have complex structures and do not fit well into a database model that is relational in nature.

Object-oriented database management systems provide the needed flexibility to support this diversity of complex data and their inherent behavior. But the low efficiencies and lack of easy-to-use ad-hoc query user interfaces of current object-oriented DBMSs make them difficult for real scientific applications. POSTGRES (Stonebacker and Kemnitz 1991, Olson 1993) is an extensible relational database management system with major object-oriented features: abstract data types, user defined types and procedures, attribute and procedure inheritance, and production rules.

Various new data types and operations have been defined for scientific data types encountered in OSIMS, such as image data types for AVHRR images, and two-dimensional or three-dimensional field data for large gridded datasets that represent the outputs of various simulation models.

MULTI – LEVEL STORAGE FOR OSIMS DATA

Because of the huge volumes of data in OSIMS, efficiency is a critical issue in the performance of the system as a whole. A large number of datasets consists of several megabytes and need to be stored and analyzed.

In addition, these datasets are rarely queryed for a particular point, but the scientists are concerned with the characteristics of the whole dataset, such as their images, their statistical attributes, etc. On the other hand the metadata of these large datasets and other management information will be queried very often. Storing all these data in one layer inevitably degrades the system performance.

Thus, we store the attributes of these large datasets and management information in relational tables, and the large datasets themselves in a unix file format that resort to the POSTGRES external large object interface. POSTGRES provides the different levels of data access, transaction management, and security control capabilities. The efficiency is achieved by having the DBMS access the metadata first. The large datasets are accessed only when needed.

DATA PRESENTATION AND ANALYSIS

The metadata of the large datasets and other management information can be presented to scientists in tabular format effectively, but large datasets are difficult to be understood or are even meaningless if presented in a tabular format. Large, time sequenced observational datasets and model outputs are meaningless if presented as raw data.

What we need is an integrated data browsing, visualization and analysis interface (Treinish 1992, Treinish 1993). In our system the metadata is browsed by relational tables, geographic and environmental data are presented by maps, large observational datasets and model output are presented by their images, geometries, or their animations.

Currently we are integrating POSTGRES, Advanced Visualization System (AVS) and the Geographic Information System ARC/INFO into a cooperating system for the OSIMS. Each of these provides a specific and individually complex functionalities (see Figure 1).

ARC/INFO provides a most powerful graphic presentation and spatial query capability for geographic data. By overlaying geographical data such as, the South Florida coast line maps, environmental and geological data (e.g. sensor locations, cleanup equipage, oil spill trajectories predictions) onto one map, the user can see the relation od critical features of the overall situation. Queries for relevant information, such as what amount of oil has been spilled in a specific place, can be directed from the icon of the visual representation.

POSTGRES provides the DBMS functionalities such as integrity management, concurrent multiuser access, independent user 'views' of centralized data, and access to the DBMS application tools such as forms and menus products. It also allows us to integrate with ARC/INFO , so that relational joins of the data in POSTGRES tables with geographic features in ARC/INFO can be made.

USING AVS AS A DATA ANALYSIS TOOL

We use the Advanced Visualization System (AVS) (AVS 1992) - a state-of-the-art visualization system with the capabilities of animation and distributed, concurrent computations - for data analysis in OSIMS.

More than 150 built in modules in AVS provide full image analysis such as image enhancement, edge detection, image transformation, and image display. Data analysis such as data sampling, data down-sizing, data filtering or data conversion and rendering such as graph viewering, or geometry viewing are also included. We have extended AVS with our own modules customized for OSIMS applications. The AVS visualization networks built on these modules provide the scientists with a unique vantage for insight into complex problems characterized by large data sets.

We have used AVS to visualize a variety of large datasets encountered in OSIMS, such as griddled 2-D fields of ocean current velocities from the ocean circulation model, time-sequenced observational data such as wind velocities, directions, air temperatures, sea surface temperatures from shore stations, and AVHRR satellite images. Currently, we are also using the AVS concurrent capability to animate the oil spill trajectory resulting from the output of the oil spill trajectory prediction model in real-time.

DBMS SUPPORT FOR SCIENTIFIC VISUALIZATIONS

Despite the virtues of visualization systems, they lack data management support. They give little built-in support for finding pertinent datasets based upon the attributes of the datasets other than providing a simple file browsing mechanism.

Oil spill researchers and responders need to collaborate in a multitask, multistage effort. This leads to the problem of multiple heterogeneous platforms as well as to problems of concurrent and timely access.

Based on the above observations, we recognized a need for a comprehensive system to support the management of scientific visualization data. The basic idea is to provide an integrated system which couples attributed-based dataset query with high performance visualizations. Even the most advanced file-based systems don't provide a solution to this problem. We are making extensions to POSTGRES to provide data management support for scientific data visualizations.

The second tactic in the subsystem is to have the AVS visualization network script, used to visualize the dataset, also stored in the database through the POSTGRES external large object interface. The pertinent large datasets are retrieved based upon the attributes of the dataset contents through a TCL/TK graphical user interface, the corresponding visualization is triggered automatically through the user interface. In this way, OSIMS researchers and decision makers don't need to invest a large effort to learn how to build AVS networks.

DSS FOR OIL SPILL COUNTERMEASURES

One can divide the oil spill decision-making process into three hierarchical levels: *strategic, tactical,* and *operational.* More specifically, the three levels can be defined as follows:

1. *Strategic Level,* where one wishes to determine the quantities, types and locations of equipment that should be stockpiled to respond to future oil spills. The estimates of the likelihood of oil spill frequency and the magnitude associated with the oil spills have to be used as inputs for making strategic decisions. The optimization models that tackle such decisions should take into account various parameters including spill frequency of occurrence, variability of spill volumes, different equipment types, fixed costs to open a facility, equipment acquisition, transportation, and operating costs, equipment efficiency and operability as a function of weather conditions, damage costs as functions of spill volumes and level of response. Stochastic modeling, along with mixed-integer programming techniques are applicable for this level of decision making.

2. *Tactical Level,* where one wishes to determine aggregate actions that should be taken to respond to a specific spill, such as what equipment should be dispatched on scene, how long that equipment should stay on scene, etc.. These actions are taken by a decision maker after the occurrence of the spill is made known. The decision maker has to address such post-spill issues as availability of equipment, performance degradation of the clean-up efforts with bad weather and uncertain movement of the oil spill. The trade-offs between the potentially high cost of oil spill damage and the high cost of clean-up operations has to be balanced. Tactical decision-making is two-fold; it consists of:

   1. *Optimal deployment of oil spill clean-up equipment:* An analytical framework can be developed to assist the decision maker to allocate optimally the available resources for cleaning up the specific spill after its occurrence is made known.

   2. *Contingency Planning:* When a spill occurs, an efficient spill contingency plan will help to limit the adverse effects of the spill. It should provide a quick and efficient response, should be economical, and should be flexible enough to adapt to the changes due to the availability and capacity of the personnel and equipment and due to the nature of the spill.

3. *Operational level,* where one examines in much more detail the act ions that must be taken on the scene, such as depoyment of booms, skimmers, dispersants, etc., to protect sensitive areas.

The DSS will also be used in the context of strategic decisions regarding location of oil spill response equipment, optimum equipment mix and effect on probable spills of alternative mixes and locations. A preliminary literature survey (Iakovou *et al.* 1994) has shown that the problem has not been fully addressed and the characteristics of tropical environments are not well understood.

Discrete optimization tools can be used to tackle this level of decision making. However, because of the computational complexity of the problem and the required storage space exact algorithms should not be employed. Rather, approximate algorithms that give near-optimal solutions can be derived.

KNOWLEDGE – BASED DSS

The Decision Support System (DSS) will serve a central role in all aspects of tactical operations. Our main concern is to aid, not replace the agent in the field, but we wish to entrain as much expertise as possible within the system. Some basic goals include automatically logging event data, providing a portable package of relevant reference material, simple inference, operating with uncertain and incomplete data and explanation of reasoning. Our single most critical concern is to coordinate the quantities of regulatory and situational data, decision procedures and method knowledge on a per task basis so that the individual user is supported and not overwhelmed by the available information. The crisis nature of oil spill management exacerbates the problem of information overload.

Knowledge-based systems are a perspicuous and direct way to represent heuristic plans of the sort found in spill response documents (Goul *et al.* 1992, Steiner *et al.* 1991, Decker 1987). They are effective in environments where there is no closed solution to the problem, but expertise does exist. A knowledge based decision support system (KBDSS) can extend system capabilities to deal with the formation, analysis and critique of plans. Such a system can suggest, rank and explore options based on preference criteria; by choosing rules that fit the situation, by applying salience measures, or by invoking and using simulation data. We intend to wrap traditional methods of DSS, GIS, database systems and interface shells, in an intelligent information system which can connect these in a more higher level manner and provide a number of further services.

A first step in constructing the KBDSS is to implement rules which contain the information typically found in the decision matrices common to response plans. A rule based system invokes rules in a chaining fashion, facts about the current situation used to infer to arrive at further facts and eventually to reach conclusions. The checklists common to response plans can be included in a rule based system as procedural knowledge, or in a less lock-step mode, as related trains of rules. This is fairly standard technology from expert systems. Current efforts are building and testing the elementary rule bases and inference techniques.

The desire to maximize use of available resources, of database, GIS and model information has led us to propose the migration to a distributed expert system of heterogeneous elements. These are sometimes called federative expert systems. Such a system should allow us to take advantage of the great amount of expertise already entrained in traditional systems, maximizing not only the response effort, but the research effort as whole.

Correct, timely and focused information is critical to effective spill response. High connectivity and communication is a double-double edged sword entailing that we both reach out to get information available and conversely that we limit the inflow of information to avoid operator overloads. Only a few simple interactions between externally created information systems will be included.

A number of benefits can be secured by creating a distributed network of independent. intelligent nodes. Where several agents could effect a task, bargaining, on whatever criteria, could be effected. Conversely, tasks delegated by a central command can arbitrated based on local knowledge. It is critical that our efforts at this point already take in account these long term goals. Three goals guide us: 1) extending the use of heterogeneous elements information systems 2) establishing, controlling and deciphering communication 3) accurately coordinating forces.

In the short- to mid-term we will create knowledge-based interface agents for those nodes in the system which do not support knowledge based reasoning. For the excess overhead, we should, be able to tap the vast amount of data collection, simulation modeling and procedural knowledge already in place. In the short-term we are focusing on retrieving/generating information on demand. In this scenario, a non-intelligent system will be driven by requests put to an intelligent interface unit (IIU). The IIU is a knowledge-based shell tailored to activate and communicate the results of the local resource, driven on command by planning agents. In the mid-term we need to expand to interaction between elements, say by bargaining simulation exactness or granularity against result deadlines. Figure 2 shows the interactions between agents and databases.

CONCLUSIONS

A regional prototype Oil Spill Information Management System has been presented. The system includes objected oriented databases, visualization systems, geographic information systems, expert decision support tools, optimization tools, and modeling and simulation tools.

Our future work will concentrate on a distributed architecture that will allow multiple heterogeneous systems to cooperate in an overall task. Since spill response actions are to be carried out with all deliberate speed, in the milieu of independent agents it becomes critical that the individual elements of the system be able to provide suggestions in real (event) time; even in the absence of complete, totally reliable situation knowledge. We are also interested in extending the essential capability of the inference mechanism to deal with time critical information that is missing, imperfect or which may possibly to be superseded. The requirement is to provide a reasonable "any-time" deduction mechanism so that it all but the most extreme cases some reasonable action can be put forward.

ACKNOWLEDGEMENTS

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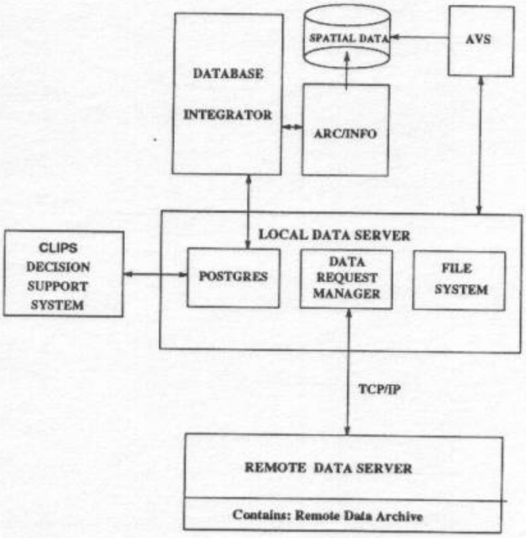

Figure 1 A PROTOTYPE FOR INTEGRATED OIL SPILL INFORMATION MANAGEMENT SYSTEM

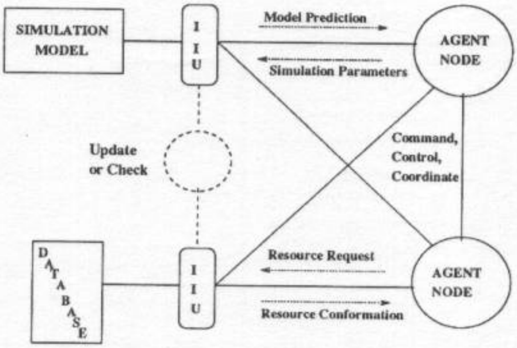

Figure 2 A SYSTEM OF INDEPENDENT AGENTS WITH INTELLIGENT INTERFACE UNITS RESPONSIBLE FOR KNOWLEDGE BASED COMMUNICATION

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ETH - CHEMRISK: A PILOT DECISION SUPPORT SYSTEM FOR INDUSTRIAL ACCIDENTS EMERGENCY PLANNING AND PREPAREDNESS

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Abstract

ETH-CHEMRISK is designed in accordance with the principles and methods of emergency planning and preparedness as applied to the case of industrial (chemical) accidents. The outline of this decision support system design follows from both the features that nuclear and chemical accident consequence analysis share, and those that make the two different from each other. It uses and integrates concepts such as: data base, geographical information system, risk assessment, graphic driven software environment.

BACKGROUND

ETH - CHEMRISK is an attempt to answer the challange of having the principles and method of emergency planning and preparedness to the case of chemical accidents. Most of the approaches, models and indicators in ETH - CHEMRISK come from the existing literature. Having in the background the well-quantified accident consequence assessment techniques in the nuclear industry, ETH-CHEMRISK is strongly supportive to the notion of Chemical Process Quantitative Risk Analysis (CPQRA). It uses specific indicators such as chemical doses, or limiting levels including the Immediate Dangerous for Life and Health (IDLH) levels, the Threshold Limit Values (TLVs), and the Short Term Exposure Limits (STEL). Proper allowance is also made in ETH-CHEMRISK for a method that, while more speculative and difficult to establish, would however increasingly gain terrain, namely the probit functions risk / consequence evaluation, that links, in essence chemical doses to their health effects - in fact, to the lethality of an environmental spill of toxic / hazardous chemicals. Though various methods -including probits- are available for quantifying the fire-related hazards entailed by chemical spills, the rather local, close-range nature of such hazards has less to do with the vocation and potential of ETH-RISK (Gheorghe et.al.,1994) to adress wider spatial distribution of hazards. All thermal and explosion related effects were left aside in the current version of ETH-CHEMRISK. While the back-end issue on how to quantify chemical accident consequences relied on the pooled wisdom at AIChE, the front-end issues of i) primary data and ii) the chemical accident source term definition were steered by a combination of selected sources and independently originated solutions. Sources of primary data were (Guidelines,1989; Diamonds,1989) for the chemical accident source term. ETH-CHEMRISK draws upon the concept and prototype software ETH-RISK, designed for nuclear Accident Consequence Assessment (ACA). This stands true, in particular, for the dispertion model employed, which is an adapted version of the short range, complex terrain-sensitive model used with the module EXPOSURE.CH in ETH-RISK. The most radical adaptation of the latter to the chemistry's terms of reference include: augmenting the plume rise routines to the effect of covering non-bouyant (ground hugging) heavy gas flows; elimination of the deposition-related components of the models and software; generally, the replacement of dry-wet, and radioactive depletion mechanisms by a single, decay-like mechanism controlled by an user-estimated "chemical lifetime"- a technique also used with other software packages (TNO,1989). Adequate procedures to account for i) instantaneous concentrations of released chemicals in air (chemical cloud position monitoring); ii) chemical doses, defined following AIChE's CPQRA methodology, as time-integrated powers of airborne concentrations of released chemicals; iii) probits and related lethality percentages. Three new software modules had to fill in. These are: NEEWMAP.WRK, DISPERS.CON, AND DISPERS. TIC. Consequent changes were made in the management of the GIS base, which is now controlled by a distinct module - NEWMAP.WRK. Moreover, given the far lower ranges in the distances to release sources that usually are of interest in a chemical accident, a new facility was added, namely to zoom over restricted zones on the 21 maps of the Swiss territory currently available with ETH-RISK, while preserving the grid resolution of 64 x 64 knots over whatever viewfield chosen.

ETH-CHEMRISK STRATEGY

The outline of the ETH-CHEMRISK design follows naturally from both the features that nuclear ACA and chemical ACA share, and those that make the two different from each other.

A Database Environment:

The fact that several hundred or more chemicals may each become the subject of an industrial / chemical accident, has as a consequence the need to endow the DSS for chemical ACA with a rather well-developed database of chemicals that may be of interest. Such a facility should be instrumental not only in listing out its members, but also in providing selection and comparison mechanisms. Listing together all chemicals of a toxicity larger than (IDLH lower than) a given limit, or sharing the same fire hazards, or having well-defined probit function coefficients are, e.g. important assets, the need of which one cannot fail to percieve. With ETH-CHEMRISK one faces a two-fold environment, created by both the GIS base and the chemical data base. In case of emergency planning, while in a nuclear accident several dozen nuclides are of concomitent interest, and on several pathways (cloudshine, groundshine, inhalation, skin deposition, ingestion, etc.), in a chemical accident a single substance is, most usually, the subject of a hazardous release. The recently enhanced interest in **"domino effects"** in chemical accidents, cannot change this essential difference, that is bound to apper in the software's structure of the ETH - CHEMRISK. The emphasis on a single chemical and its physico-chemical characteristics is expressed, in the case in question, in the module CHEMDATA.WRK-an independent data base manager- handling 25 sequential files each holding a physico-chemical parameter, or feature of interest, for several hundred chemicals and their synonyms totalling 701 entries. Once a chemical is pointed at as the subject of an accident, all the other code modules would work on it, and only on it.

A Complex, Fluent Source Term Facility:

The present software includes a complex module that would be able to simulate a chemical release that may start as a liquid, continue with vapours, and end up as a gas outflow. The module SOURCE.WRK identifies the quantities of evacuated chemical that become airborne; this is to be further used with the dispersion models. Since the notion of chemical risks in chemical accidents would relate to rather short term exposures, the information that dispersion models are expected to provide should basically answer the following questions:

i) where is the chemical cloud at a given time, and how intense the chemical concentration in the cloud is ?; and

ii) what is the effect of the cloud passage, integrated over rather short times (15-30 minutes)?

Chemical Clouds and Their Time-Integrated Effects:

In ETH - CHEMRISK, answers to the first question are provided by module DISPERS.CON, whereas for answering the second question the module DISPERS.TIC was developed. Both modules would basically rely on the trajectory-puff model. The output of these models is given in a GIS style. However, it must be stressed that a full development of this DSS instrument would require detailed, close adaptation of the flow-cum-dispersion models in ETH-CHEMRISK to the topography of urban areas, perhaps beyond the model's currernt potential to account for these.

Impact Evaluation:

The GIS grid style is used to hold the information that is relevant for the impact of chemical accidents. Grids may hold airborne concentrations at a given time (mg/m^3 or ppm) when one runs DISPERS.CON, and time-integrals over determined, user-chosen durations, of certain chemical-specific powers (0.653...2.5) of the airborne concentrations, known as **"chemical doses"**. Once concentrations or doses are grid - mapped by using a GIS environemnt, several possibilities are open (one may compare concentrations in a cloud at a given time). The technique of paths of minimum exposure developed in a nuclear emergency planning environment is fully functional also with ETH - CHEMRISK. Such paths can be easily mapped either with respect to the instantaneous positions of the travelling chemical cloud, or to its time-integrated effect (chemical dose).

ETH-CHEMRISK MODELS

There was a need in ETH - CHEMRISK for a variety of models to cover the varied phenomenology involved in a chemical accident with "off site" consequences. A tractable model was designed to determine the physical state of chemicals in their storage containments. A many-faceted outflow model had to take care of the transition from liquid discharges to vapours, and then to gases- the distinction between the last two varieties following from the assumption that vapours are ejected from punctured vessels containing liquids at a constant (vapour) pressure required by the vessel temperature, while gases are evacuated adiabatically, at decreasing pressures (and temperatures) as liquids were exhausted, till the vessel pressure equals ambient pressure. Dispersion models adopted for chemical accidents were generated from the original close-range dispersion model in ETH-RISK. And a **dose-effect relationship** had also to be adopted, from the referenced literature, to fit the case in point. The main aspect to be solved was to find a workable way to determine what mass and volume fraction from a given mass of chemical, squeezed into a storage vessel of given shape and volume, is in liquid state-the remaining space being assumed as occupied by saturated vapours at equilibrium with the liquid. Physical state models were used as a substitute to more accurate knowledge of the relationship of vapour pressure to temperature. Six outflow modes were assumed as possible, for a chemical in a vessel to escape into the environment. The chemical may emerge as: liquid, two-phase mixture, vapours (critical or subcritical outflow), gas (critical or subsonic outflow). Module SOURCE.WRK is able to monitor in a fluent manner the entire process descriebed above, starting from the determination of the liquid fraction in vessel and continuing with a sequence of outflows as appropiate.

Takeoff Models:

It is important to note that what matters is the accident's source term in not only how much substance gets per time unit, but also, how much substance gets airborne (and thereby available for atmospheric transport and dispersion). The following systematics was used: i) gas outflows and vapours outflows would go directly airborne; ii) for the two phase outflows, a simplified, conservative approach was taken in the sense that all substance that come out two-phase is assumed to totally flash in gaseous form as ejected, and becomes airborne; iii) for the liquid outflow, several cases were considered (ambient temperature above liquid's boiling temperature, ground temperature is higher than liquid's boiling temperature, ambient temperature is below boiling temperature etc.).

Dispersion Models:

ETH - CHEMRISK features a combination of trajectory and puff models. The *trajectory component* is sensitive to a variety of circumstances such as topography, latitude, time of the year, time of the day, dominant winds, insolation, atmospheric stability and inversion regime etc. Trajectory model's basic control parameters are: source related (geographical coordinates, time of emission, height of emmission), meteo related (stability category, wind speed at 10 m height, direction etc), model specific (reference gradient coefficient and barometric exponent, solar factor, inversion layer exponent, reference friction coefficient, geostrophic ratio, reference mass factor. The *diffusion component* of the model relied on the notion that, instead of displaying a purely "molecular - gaussian" structure, plumes of pollutants are rather fractal in nature. A note is in order about placing rainy areas on maps. The idea was to construct an irregularly-shaped rainy area from circular "primitives". By exercising some ingenuity in overlapping such "primitives" one may, in principle, simulate rains of an arbitrary coverage and timing.

Dose - Effect Models

The following chemical risk indicators are used in the present structure of the ETH-CHEMRISK: IDLH, TVL, STEL, Toxic Dose, Probit Functions. One can map the values of all these indicators. Modules in the ETH - CHEMRISK decision support system feature a viewing option. This is to be used to get a variety of viewing angles as well as to zoom on the maps at work. Under probabilistic or deterministic assumptions regarding various parameters in the models' structure, the ETH - CHEMRISK converts, if so deemed, toxic doses to probits, and the latter to likely lethality percentages, and has these maped over the geographic base environment.

SOFTWARE STRUCTURE

ETH-CHEMRISK is built upon two intertwinned platforms. One is ETH-RISK's geographical base, and the other is the chemical data base developed for this code package only. The following is an enumeration of the main operative components of ETH-CHEMRISK:

- CHEWMDATA.WRK - the data base manager;
- SOURCE.WRK - the chemical source term;
- NEWMAP.WERK.- allows the selection of one out of a number of maps- relief and road network included, as well as the isolation of a restricted viewfield around the source of release;
- DISPERS.CON - under probabilistic or deterministic assumptions regarding the wind regime, and considering time of the year and day, insolation, topography, atmospheric stability, plume rise etc. monitors the chemical cloud position as the cloud travels with the winds over the territory;
- DISPERS.TIC - under probabilistic or deterministic assumptions, monitors toxic doses as these accumulate during cloud's passage. Converts, if so deemed, toxic doses to probits, and the latter to likely lethality percentages, and has these maped over the geographic base.

USING ETH-CHEMRISK

ETH- CHEMRISK was designed to assist the emergency planning preparedness and simulation process. It allows the simulation of various scenarious and saving these scenarious in an *ad-hoc* database which later can be recalled; the information should be used in emergency planning decisions and land use planning. Some caveats are in order:

- being computation and graphics-intensive, ETH-CHEMRISK would prefer machines as fast as available;
- colors are of consequence with ETH-CHEMRISK. Its thematic maps may indeed look senseless in a black and white environment. An archiving facility is available at runtime with the executive modules. The respective de-archiving facility known as ALBUM includes an option on color changes that may help in getting better contrasts on black and white printers. ETH-CHEMRISK was tested for a variety of unexpected interrupts. However, at this stage in the experiment one cannot guarantee that some, unthought of, manoueuvres cannot block the system.

CONCLUSIONS

ETH-CHEMRISK is an exercise in applying to the case of chemical accidents several assets percieved in the ETH-RISK approach and, in particular i) the notion of an extensively interactive and transparent input machinery to cover a variety of "what if.." type of problems warranted in an abnormal chemical event; and ii) the setting of the entire endeavour in an appropiate data base, and a GIS-oriented, graphics driven software environment.

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AN EXPERT SYSTEM FOR THE ON-SCENE MANAGEMENT OF HAZARDOUS MATERIALS INCIDENTS

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ABSTRACT

Every year a substantial amount of hazardous materials is transported internationally. The danger associated with accidental release of hazardous materials is substantial and sometimes catastrophic for the humans and the environment. The magnitude of the consequences of accidents involving hazardous materials shipments depends to a great extend on the effectiveness of the emergency response units dispatched at the scene of an incident.
The objective of this paper is to develop an expert system for the effective on-scene management of hazardous materials incidents. In particular, the developed KBES (Knowledge Based Expert System) aims to support the central dispatcher, who coordinates all the agencies involved in the incident management response, determine appropriate removal and clearance actions, dispatch and coordinate the required crew.

INTRODUCTION

The danger associated with accidental release of hazardous materials is substantial and sometimes catastrophic for the humans and the environment (Zografos and Davis, 1989). Therefore, concern about risks associated with hazmat has prompted development of incident management systems aiming to minimize the effects of an incident. An incident management system is the coordinated pre-planned or real time use of human, resources and equipment in order to reduce the duration and impact of incidents. Incident management systems, in general, exhibit differences in terms of their organization and structure but all share the following functional elements: a) Detection, b) Response and 3) On-scene management and clearance.

This research is focused on the third element of incident management because the on-scene management of hazardous materials accidents involves a wide spectrum of actions and complicated decisions where expert judgment is involved. The characteristics of the on-scene management problem suggest that the utilization of expert systems can enhance the quality of hazmat risk management decisions.

The objective of this paper is to describe the structure of an expert system for the effective on-scene management of hazardous materials incidents. The scope of the proposed KBES is to aid a central dispatcher in determining the appropriate removal or clearance actions, dispatch the pertinent equipment and coordinate the required private and public agencies. The agencies participating in the hazmat incident management actions are: a) the police department, b) fire department, c) traffic management center, d) medical centers, e) shipping companies, f) radio and television stations, and g) special incident management teams.

DESCRIPTION OF PROPOSED KNOWLEDGE BASED EXPERT SYSTEM

Managing hazamat incidents is a complex problem where different parties referred as stakeholders (Keeney, 1980) (i.e., government, shippers, emergency responders) are involved. Many tasks in the incident response procedure are so complex and ill-structured that conventional analytical tools are of limited use. Nevertheless, these tasks are addressed, and problems solved using human judgment and experience.

Expert systems are designed to emulate the performance of an expert or a group of experts in a particular problem domain and are primarily applicable to situations, like hazmat incident management, requiring specialized knowledge, skill, experience or judgment for determining a solution strategy. Many applications of expert systems on problems where human behavior, social and political considerations and decisions are involved can be found in literature (Yeah et al, 1986).

Transferring the expertise and knowledge from one or more experts to a computer program is the major task in building an expert system. The following steps give the outline of the expert system building procedure followed in this research (Roth et al, 1983):

Problem Identification.

The first step in building an expert system is to identify the area, concepts, and characteristics of the problem. In addition, the participants and their roles, goals, constraints and resources (time, labor, and computer facilities) needed or provided. In this step the involved agencies, in cooperation with the knowledge engineer, define the nature of the problem, the expectations that the system must fulfill and the skills of the KBES users (experts or non-experts). In the case of hazmat incident management 'central dispatcher'' evaluates the circumstances, at the accident site, determines the incident nature and appropriate response.

Knowledge acquisition

Knowledge acquisition is the most difficult stage in the KBES development process. In our case knowledge was acquired from various sources: a) Interviews with chemical engineers expert in packing and transporting hazmat, b) literature review in the area of hazmat transportation (US DOT, 1990), (CANUTEC, 1992), c) fire department, and d) private companies specialized in responding to incidents with great environmental impact (e.g., oil spills). The knowledge acquisition process revealed that the following steps are used when responding to hazmat incidents: 1) Incident detection 2) Incident verification 3) Transfer of information to central dispatcher\emergency response advisor, 4) Determination and application of the appropriate response scenario, and finally 6) monitoring and evaluation of incident condition.

Formalization and implementation

The proposed KBES simulates the central dispatcher who receives incident related information from a hazmat incident site. His\her first effort is to identify the type of spilled hazmat by: a) checking shipping documents (when possible) to determine the type of spilled material or at least identify the corresponding product identification number (PIN) and\or 2) the placard displayed on the ends and sides of a tank, vehicle, rail car, etc. If this information is not available then the shape of railcar or road trailer can provide useful hints for the type of spilled hazmat. The identification procedure is shown in Figure 1.

The next step in the incident management procedure is to determine more information about incident conditions, incident types, and severity e.g., fire, spill or leak existence etc. The dispatcher combines all the input information, evaluates the situation, matches the accident type with a similar one that exists in a library of events and determines the appropriate response actions, dispatches and coordinates appropriate agencies. This library of events, embedded in the proposed KBES, contains different types of events\incidents. The proposed KBES is an integration of various databases found in the literature and the heuristic knowledge and expertise obtained by interviewing experts. The algorithm used in the proposed KBES is known as '' *describe -and-match* '' algorithm (Vasilakis, 1994), (Winston, 1992). This algorithm has three steps:

⇒ Describe the incident and its nature using suitable representation and variables

⇒ Match the incident description against library descriptions until there is a satisfactory match or there no more other library descriptions

⇒ If you find satisfactory match announce it; otherwise announce failure

The steps involved in the implementation of the "describe and match algorithm" is shown in Figure 2. In particular, the central dispatcher transfers the information, reported by the crew at the incident site, to the KBES and the system attempts to match the reported event with the events stored in the library, selects the one that matches the existing situation, and selects the appropriate response.

The KBES requires a large number of variables, determined in real time by the central dispatcher, to operate. The system prompts the user to define the values of some variables, in order to identify the nature of the hazmat incident. For example the hazmat type, determined by the person reporting the incident at the incident site and the dispatcher (see Figure 3), environmental conditions (e.g., air, temperature, time of day), vehicle type, packaging type, injuries, specific information (e.g., fire, leak etc.) are the cornerstone for the KBES to operate properly. Obviously the system uses a large number of user defined variables and options which are not presented in this paper.

The KBES contains a library of almost 2500 hazmat. Materials that require similar treatment in case of an incident are grouped together and 52 groups were identified [6]. Therefore, 52 different response scenarios "guides" were constructed and the problem magnitude decreased significantly.

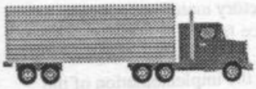
The structure of the proposed system is shown in figure 3. It details three data bases:

1) Database #1 that contains hazmat (almost 2500) classified according to their PIN number/of name and the corresponding "response guide". Example:
SHIPPING NAME: Sodium Peroxide *PIN:* UN1504
GUIDE: 28

2) Database #2 that contains CHARTS and LABELS of PLACARDS (25 totally) and corresponding response guide. Example:

corresponds to guide 018

3) Database #3 that contains different truck types (17 totally) and the corresponding response guide number. Example:



corresponds to guide 01

The first step of the proposed hazmat incident management system is to run the "guide # selection routine" shown in Figure 1 and extract from the aforementioned three data bases the appropriate guide number.

In the second step, the KBES is activated (Figure 3). Depending on the number of guide determined at the previous step the appropriate routine is activated (totally 52 routines are embedded in the KBES). For example if guide #18 is appropriate then routine # 18 is activated from the library of events and the user must define some variables to accommodate the proper operation of "describe-and-match" algorithm. The system then is able to state the appropriate recommendations in terms of potential hazards (fire\explosion and health), public safety (evacuation procedure, injury assistance if needed, etc.) and emergency response (fire extinguishing techniques, spill or leak removal, traffic detouring, etc.).

In more details, the proposed KBES provides information and recommendations about the protective clothing for the response team, evacuation, fire fighting, first aid and immediate medical assistance, and efficient management of an emergency. Factors considered for the evacuation procedure are: population at risk, hazmat quantities, hazmat properties, time of day, local weather and terrain conditions. In terms of fire fighting requirements the foam type is recommended.

Test Example

The following example is used to demonstrate the capabilities of the proposed KBES.

A truck transporting hazardous materials overturned. The truck driver is injured. The weather is rainy and a small fire and leak was reported. Time of day is afternoon and traffic near the incident site is light.

The KBES prompts the user to define the type of spilled material. The officer at the incident site reported PIN number UN 1504. The KBES scans the database and determines that the spilled material is Sodium Peroxide therefore, guide # 28 is applicable. Routine # 28 is activated and the user inputs the information. Finally the system comes out with the following suggestions; these suggestions concern the following areas:

Potential Hazards:
a) FIRE OR EXPLOSION
Attention the Sodium Peroxide reacts vigorously and\or explosively with water!!!
It produces poisonous and\or corrosive substances on contact with water
Runoff may create fire or explosion

b) HEALTH
Inhalation or contact with vapor, substance, or decomposition products may cause severe injury or death.
Fire was reported!!! Be careful fire will produce irritating, poisonous and\or corrosive gases and run-off from fire control or dilution water may pollute waterways.

Public Safety:
Leak was reported!!! Leak area should be isolated immediately for at least 50-100m in all directions. Keep upwind and out of low areas!!!

a) PROTECTIVE CLOTHING
Wear fully encapsulating, vapor-protective clothing!!!!

Structural firefighter's protective clothing is not effective

b) EVACUATION
The spill is small and no large containers are involved in the fire NO further evacuation is required.

Emergency Response:
a) FIRE
ATTENTION!!!! DO NOT USE WATER OR FOAM
The fire is small therefore use dry sand, dry chemical, soda ash or lime or withdraw from area and let fire burn.

b) LEAK
Eliminate all ignition sources (no smoking, flares, sparks or flame in immediate area).
Do not tough or walk through spilled material
Stop leak if without risk
The leak is small therefore cover with dry earth, sand followed with plastic sheet to minimize spreading and contact with rain.

First Aid:
A victim was reported at the incident site !!!
Remove victim to fresh air. Apply artificial respiration if victim is not breathing. CAUTION!!! do not use mouth-to-mouth methods if victim ingested or inhaled Sodium Peroxide; use the Holdger-Nielsen method (back pressure-armlift). If breathing is limited administer oxygen. Remove immediately contaminated clothing and shoes. Remove material from skin immediately. In case of contact flush skin with running water at least 15 minutes.

FOR THE DISPATCHER:

Call an AMBULANCE!!! But do not forget to inform the ambulance crew about the situation so they be prepared to handle the situation. Announce the situation to the public through radio and television, so people will avoid that area. Finally, organize traffic detouring process and dispatch appropriate police crew to realize your detouring scenario.

CONCLUDING REMARKS

An integrated KBES was developed as part of this research effort. The proposed KBES is not a substitute for emergency response training, experience and sound judgment but aims to facilitate the emergency response and prevent a catastrophe. It helps the emergency response dispatcher to determine appropriate response actions faster, easier, and the non-expert to behave like an expert and respond promptly and accurately. It is user friendly, providing explanation facilities on every level and from the programmer's point of view the system is transparent and modifications can be made easily and quickly. Finally, it manages a great amount of data and information faster and with greater accuracy than a human does.

Acknowledgments

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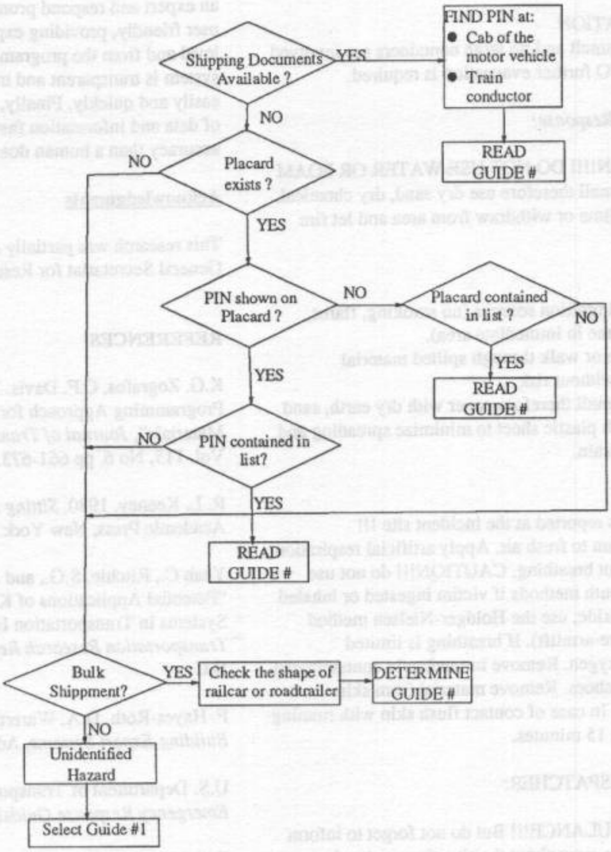

FIGURE 1: ROUTINE FOR "GUIDE #" SELECTION

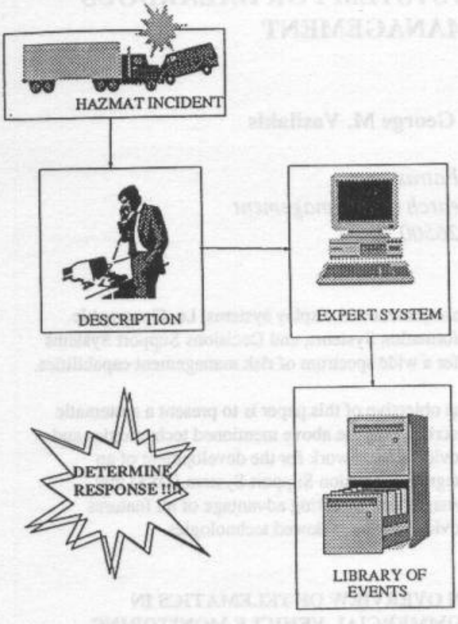

FIGURE 2: DESCRIBE-AND-MATCH ALGORITHM

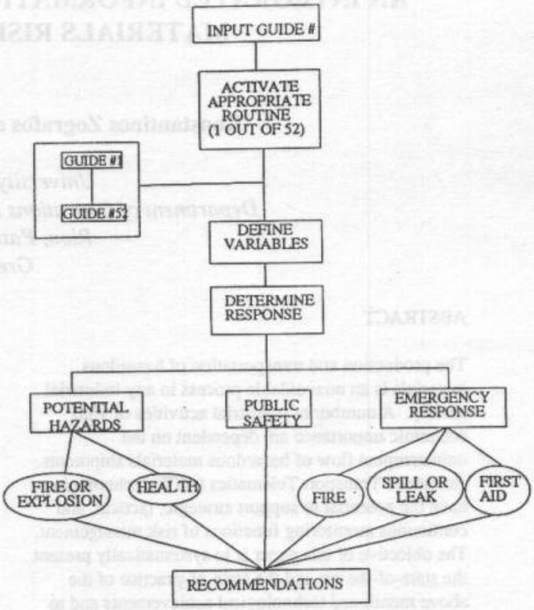

FIGURE 3: STRUCTURE OF THE PROPOSED KBES

AN INTEGRATED INFORMATION SYSTEM FOR HAZARDOUS MATERIALS RISK MANAGEMENT

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ABSTRACT

The production and transportation of hazardous materials is an unavoidable process in any industrial society. A number of industrial activities of vital economic importance are dependent on the uninterrupted flow of hazardous materials shipments. Advanced Transport Telematics (ATT) technologies have the potential to support strategic, tactical, and continuous monitoring functions of risk management. The objective of this paper is to systematically present the state-of-the-art and the state-of-practice of the above mentioned technological achievements and to assess their importance in hazardous materials risk management.

INTRODUCTION

The substantial amount of hazardous materials transported annually worldwide constitute a great potential danger for the society and the environment prompting public and private agencies to find efficient and effective ways and methods to eliminate risk related to hazmat incidents. Prompt and accurate detection and effective management reduces the impact of hazardous materials incidents and eliminates the potential societal and environmental risk. The rapid technological development provides new opportunities in risk reduction when hazmat are transported. In particular, ADVANCED TRANSPORT TELEMATICS technologies (ATT) promise to have dramatic impact on the way hazmat transportation functions will be performed in the near future. Advanced Transport Telematics (ATT) technologies have the potential to support strategies, tactical, and continuous monitoring functions of risk management actions related to hazardous materials transportation.

Automatic Vehicle Location (AVL), Automatic Vehicle Identification (AVI), Collision Avoidance System (CAS), On Board Computer (OBC) technologies coupled with integrated communications, data management and display systems, i.e. Geographic Information Systems, and Decisions Support Systems offer a wide spectrum of risk management capabilities.

The objective of this paper is to present a systematic description of the above mentioned technologies and provide a framework for the development of an Integrated Decision Support System (DSS) that manages risk by taking advantage of all features provided by the reviewed technologies.

AN OVERVIEW OF TELEMATICS IN COMMERCIAL VEHICLE MONITORING TECHNOLOGIES

Automatic vehicle identification is a system that consists of two major components: a) an on board component and b) a roadside component. The on-board component is an electronic tag that has a unique identification signature and the capability to store information describing the type of vehicle and its load. The roadside device is a "reader" that interrogates the tag and extracts the information stored in it. The information extracted from the tag can be transmitted to a computer located at a vehicle control and monitoring center. The operation of a typical AVI system is presented in Figure 1.

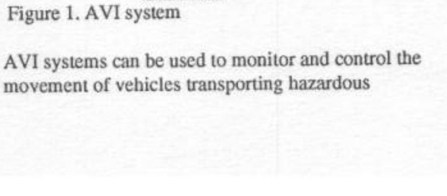

Figure 1. AVI system

AVI systems can be used to monitor and control the movement of vehicles transporting hazardous materials. This can be achieved by equipping hazmat trucks with the appropriate transmission tags and by installing "tag-readers" at crucial monitoring locations along a corridor or a network heavily traveled by trucks carrying hazmat. The AVI systems can provide essential input information for the effective management of incidents involving hazmat vehicles. In particular, the AVI system can identify truck location, and route, and display all the information at a central control center. Monitoring the truck movement in relation to a planned timetable and a predefined route can help the control center to: 1) identify deviations from a predetermined schedule and route 2) provide crucial information required for monitoring the movement of hazmat shipments, and 3) enforce hazmat routing and scheduling regulations. For instance, (Figure 2) if the control center receives a signal that the truck passed Point #1 and after a significant time period it did not pass Point #2 there is an indication that something abnormal happened (i.e. the truck is stalled, incident or the driver did not followed the redefined route).

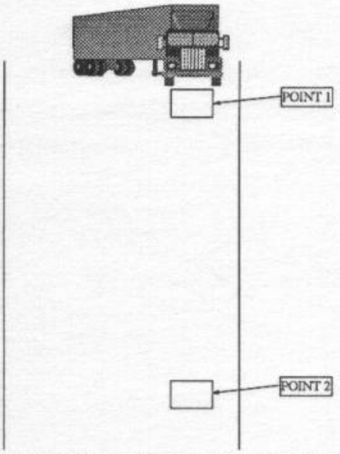

FIGURE 2. Truck monitoring using AVI technology

Alternative AVI technologies have been developed for monitoring commercial vehicle operations (Boghani, 1990); these technologies involve Low-Frequency (RF), Microwave (RF), and Optical Bar Code.

The objective of *Automatic Vehicle Location(AVL)* is to identify the current position (location) of specially equipped vehicles. AVL systems are vital for monitoring hazmat truck movements and managing hazmat incidents. Knowledge of the exact position of a vehicle transporting hazardous material can eliminate drastically the response time in case of an incident. Integrated AVL and Geographic Information Systems (GIS), provide the very interesting feature of plotting truck's path and current location on a digital map at the control center and at the truck cab, helping the operator at a control center to monitor hazmat truck movement and determine the location of an incident and provide rerouting information to the cab driver.

Vehicle location is identified by using various techniques:

- Dead-reckoning system- "inertial guidance"
- Ground Based Determination System
- Low earth orbit satellite-based system (GPS)
- Radio Determination Satellite System (RDSS)
- Proximity system-radio tags

Details about the technical and operational characteristics of the above mentioned systems can be found in references (Greenback et al, 1988), (Boghani, 1990), (Davies et al, 1991).

THE PROPOSED METHODOLOGICAL FRAMEWORK

The danger associated with accidental release of hazardous materials is substantial, therefore the development of an integrated Decision Support System aiming to reduce the risk of transporting hazmat is vital. This system must take advantage of the capabilities provided by modern technology. In the case of a hazmat incident ATT technologies provide vital information to assist incident management procedures and minimize their catastrophic societal and environmental impacts. For instance information regarding the location of a hazmat truck and monitoring of its movement, results in: a) significant reduction of incident detection, response and clearance time, b) reduction of emergency vehicle dispatching time, c) accurate and quick activation of traffic detouring and area evacuation plans, and finally, d) implementation of a plan that informs public about the situation (type of incident, severity, precautions, etc.) to prevent undesirable post-incident consequences. Therefore, ATT technologies can reduce the likelihood of severe post-incident consequences and the likelihood of incident impact.

The proposed Integrated Risk Management Information System consists of various components. At the first step spatially distributed data are collected. In particular, information regarding: the condition of a hazmat truck from On Board Computers (OBC), the location of AVL\AVI, and Traffic Management information are transmitted to a central control center and this information is combined and integrated in the computer of an Emergency Response Center. The next step, is to integrate the above information with a Geographic Information System (G.I.S) which allows the monitoring and display of the trucks transporting hazardous materials on a digital map. The operator at the central control center monitors the movement of the truck and gives on line feedback information to the driver through the communication system. In case of an hazmat incident, the second component of the Transportation Risk Management Information System is activated. This module consists of a database containing different hazmat types and appropriate response actions in case of an incident. The information from the database (i.e., incident type, response and clearance actions) and from the G.I.S. (i.e., exact location, population exposed in risk, land use, etc.) is transferred to analytical models and an expert system. The analytical models in cooperation with the expert system provide recommendations for both the operator at the central control center and the driver. The proposed system is shown in Figure 3.

CONCLUDING REMARKS

An Integrated Information System for Hazardous Materials Risk Management has been presented. The proposed system integrates available technologies for acquisition, transmission, and processing information regarding the location of hazardous materials shipments with analytical models and decision tools. The proposed system can help emergency response to reduce their response time and consequences to reduce the risk of hazardous materials transportation. Work in progress involves the detail quantification of the risk reduction benefits expected from the introduction of ATT technologies and the cost effectiveness evaluation of the proposed system.

Acknowledgments

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TIEMEC '95

RESEARCH

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Modeling Techniques for Emergency Management Systems

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THE DEVELOPMENT OF A COMPUTERIZED CROP-SPECIFIC DROUGHT MONITORING SYSTEM

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KEYWORDS: drought monitoring, crop growth models, geographic information system

ABSTRACT

A near real-time crop-specific drought monitoring system (DMS) that combines crop modelling and a Geographical Information system (GIS) has been developed in South Africa. The system is intended for use in decision support by resource managers concerned with drought aid. The condition of maize, wheat and rangeland can presently be monitored in the DMS. The system is a spatially distributed system with individual simulations being run for areas covering approximately 14 km^2. Values of the weather elements used to drive the models, are obtained through interpolation of ground observations and processing of weather satellite imagery. Monitoring is undertaken throughout a production season, with updates provided on a fortnightly basis. Predictions of expected yield at the end of the season are made by using observed data up to the current date and completing the season with surrogate historical weather data. Appropriate surrogate scenarios are chosen based on the current season. After each monitoring run, simulated yield predictions for the season are compared with expected long-term yields of the crop produced in a particular region. A drought index class is assigned based on this comparison. Maps and tabulated information are produced in the GIS showing the spatial distribution of drought stricken areas and the intensity of drought in these areas. The maps and tables are distributed to government institutions and agricultural co-operatives.

INTRODUCTION

Drought occurs the world over and through the famine that it engenders has probably claimed more lives than any other natural disaster (Riebsame 1991). Droughts are unique in that unlike floods, earthquakes, or hurricanes; during which violent events of relatively short duration occur, droughts are more like a cancer on the land that seems to have no recognized beginning (Mather 1985).

The African continent is particularly drought prone. Drought in the semi-arid regions of Africa is a recurrent but aperiodic phenomenon (Glantz 1987). The southern tip of Africa and South Africa in particular is not excluded. Considerable agricultural production takes place in South Africa under arid or semi-arid where drought is a recurring hazard (Bruwer 1989).

The term drought however means different things to different people (Day 1991). Wilhite and Glantz (1987) group drought definitions into four types:

* Meteorological drought - defined solely on the basis of the lack of rainfall and the duration of such dry periods,
* Hydrological drought - definitions concerned with effects of drought on surface or sub-surface hydrology,
* Agricultural drought - links various characteristics of meteorological drought to agricultural impacts, and,
* Socio-economic drought - definitions that express features of the socio-economic effects of drought, but can incorporate features of meteorological, agricultural and hydrological drought.

This paper focuses on the development of a near real-time, crop-specific, agricultural drought monitoring system for early warning of impending disaster. The system is intended for utilization in decision support for resource managers.

SYSTEM DESIGN CRITERIA

Drought is a spatially related phenomenon (Karl and Koscielny 1982; Mather 1985). The first requirement of a drought monitoring system then is an ability to describe drought intensity quantitatively on a spatial basis (Bruwer 1989; Shelly 1991).

The second requirement for an agricultural drought monitoring system is that the sensitivities of specific crop growth stages to drought, must be taken into account (Easterling and Riebsame 1987). A plant's demand for water is dependent on the prevailing meteorological conditions, biological characteristics of the plant, its stage of growth, and the physical and biological properties of the soil (World Meteorological Organization 1975). The monitoring system must be a synthesis of these factors.

The third requirement is that the output from such a system will be readily usable by decision makers involved in drought planning or drought relief management. The typical decision maker weighs a wide variety of inputs in reaching a decision (Redmond 1991). Presenting information succinctly will assist in sound decision making. A useful way of presenting drought information to decision makers is through the use of an index. A major reason for using indices is that they are simple, usually consisting of a single number, which is easy to remember (Redmond 1991). The fourth requirement of an agricultural drought monitoring system is that the index used should be easily updated from observed weather data obtained from the national observation network.

The fifth requirement is that an agricultural drought monitoring system should be crop-specific. Meyer, Hubbard, and Wilhite (1993) point out that the advantages of a crop-specific drought index are threefold: (i) weather's probable impact on crop production can be assessed any time during the growing season using standard meteorological variables, (ii) probabilities of projected outcomes can be assigned based on historical climate data, (iii) specific outcomes can be inferred using climatological analogs.

SYSTEM DESIGN PROCESS

The first step in the design process was to decide on the base unit to use when describing drought severity quantitatively on a spatial basis. The base unit chosen covers an area of 2° of longitude and 1° of latitude. This base unit was selected as it is a common division used by the Surveyor General for topographical and cadastral mapping and many thematic maps produced by other organizations (eg soil maps) also use these boundaries. These maps are known as the South African 1:250 000 map sheet series. There are a total of 70 such map sheets on which South Africa is mapped.

The second step in the design process was that of satisfying the requirements that the system should be sensitive to crop development stage and that it should be crop-specific. Applying crop growth models in the drought monitoring system was decided on as the solution. Selection of the particular crop model to run for a given map sheet or part thereof, would depend on the geographic area mapped and the time of year.

The models and their input data would however have to be spatially distributed. It was decided to divide the base unit into a number of smaller cells for which simulations could be performed. Each base unit was divided into cells covering an area of two minutes by two minutes of latitude and longitude (± 14 km^2). There are thus 1800 grid cells (60 columns and 30 rows) in one such unit.

The third step in the design process was to decide on a mechanism to use in determining drought severity, for a particular crop in a particular area. It was decided to use the probability distribution of crop yield as the norm for defining drought severity.

Yield norms would be obtained by using crop modelling to establish the cumulative probability distribution function (CDF) of a particular crop for given soil, climate and management (planting date, density and row widths) combinations. The CDF would be subdivided into classes to obtain threshold levels for the drought index classes (Table 1). The same approach as used in the Palmer Drought Severity Index (Palmer 1965), where numerical values are linked to brief definitions of drought intensity, was followed.

Table 1 Drought index class definition

Index	Description	Range in probability of non-exceedence on CDF of seasonal yield (%)
1	Extreme drought	0 - 10
2	Severe drought	>10 - 20
3	Moderate drought	>20 - 30
4	Mild drought	>30 - 40
5	No drought	>40 - 100

The final step in the design process was to plan the functioning of the DMS, for regular drought monitoring during a production season, such that the requirements for easily comprehensible output and readily updateable indices could be met.

It was decided that a fourteen day interval would be used for reporting on the drought situation. However the system would be designed so that the interval could be shortened if so desired. Simulations would be performed using the observed weather data series up to the current calendar date and completing the season with surrogate data. Final expected grain yield for each of the 1800 cells within the bounds of map sheet would be forecast.

Three scenarios would be used to complete the weather data series for the simulations: i) the season continues below normal (rainfall of the 1st decile), ii) the season continues normally (median rainfall), and iii) the season continues above normal (rainfall of the 10th decile). Surrogate weather scenarios would have been previously established for each homogeneous climate zone. The homogeneous climate zone within which a cell lies would be identified in choosing the appropriate surrogate data set.

The grid of forecasted yields for below, above and normal seasons would then be fed into the GIS. Here the yield forecast for each cell would be compared to the CDF of the particular crop, for its particular soil, climate and management situation. On the basis of this comparison a drought index value would be assigned to each grid cell. Maps and tabulated information produced from the GIS would then be distributed to decision makers.

The system designed would be iterative, continuing to the end of the season, with the observed weather data base increasing while less use would be made of the surrogate data base. The drought monitoring system designed is shown in Figure 1.

INITIAL TESTING

The DMS, as described above, was implemented and tested on three 1:250 000 map sheets covering the main summer grain producing areas in South Africa. Three historical production seasons, for which yield data were available, were examined; namely 1988/89, 1991/92 and 1993/94. The maize growing season of 1991/92, was a season of severe drought and therefore a good test of the system. Above average yields were achieved in the 1988/89 production season while for 1993/94 yields could be considered as normal. The system was tested both quantitatively and qualitatively. Qualitative assessment was done by showing maps from the DMS to persons familiar with the area and obtaining their comment. Quantitative assessment was done by comparing magisterial district average maize yields recorded by the Department of Agriculture, with magisterial district averages computed from the system.

Some of the maps produced from regular monitoring of the 1991/92 season, using the median rainfall scenario to complete the season, are shown in Figures 2a - 2c. Figure 2a, shows the prognosis for the remainder of the season shortly after the crop has been planted. Here it can be seen that even if normal rainfall were to occur for the remainder of the season many areas would experience yield losses as a result of drought. Rainfall in the latter part of December and early January altered the prognosis. In Figure 2b it can be seen that the situation in the south east of the map sheet has improved with moderate or mild drought losses predicted if the rainfall remained normal.

The critical flowering period of the crops occurred towards the end of January and beginning of February when virtually no rain fell. The devastating effect of this is apparent in Figure 2c, where most of the areas on the map sheet are marked as extreme drought which resulted in almost entire yield loss. The effect of isolated rain in the area covered by the south west corner of the map sheet can be seen in that the prognosis for certain areas was that normal yields would occur. The general trends shown in the three maps were verified in the quantitative analysis.

The results of the quantitative analysis are shown in Figure 3. From Figure 3 it can be seen that the DMS and the Department of Agriculture data agree well for the 1988/89 and 1991/92 seasons. The discrepancy in the 1993/94 data can be ascribed to rainfall data interpolation method used. The interpolated values for certain cells appear to be higher than what was recorded, resulting in higher yields in these cells and consequently a higher average.

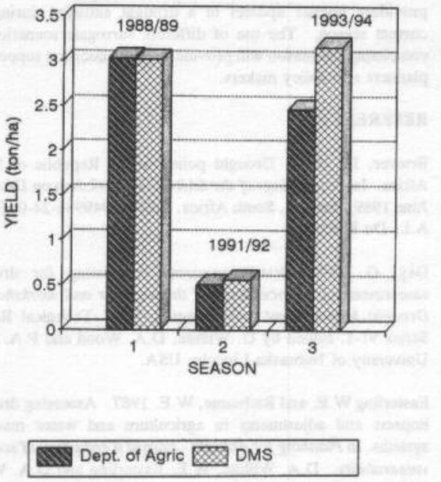

Figure 3 Comparison of Dept. of Agriculture average maize yields and Drought Monitoring System (DMS) average maize yields.

CONCLUSIONS

A crop-specific drought monitoring system, based upon simulation models, has been developed, implemented and tested with excellent results. The PUTU suite of crop growth models was successfully adapted to work on a spatially distributed grid, in order to compute an objective crop-specific drought index on a daily basis. Mechanisms to obtain, process and interpolate the weather, soil and crop data inputs required for running the models have been established and tested.

The crop modelling approach to drought assessment takes the interaction of the soil, plant and atmosphere into account. The important influence of both the amount and timing of rainfall in relation to crop growth stages is reflected in the index. A major requirement for an effective and reliable drought index is that it should be crop and region specific. The present system ensures this by using the cumulative probability distribution function for each homogeneous climate zone as an accurate norm against which current season performance is compared. This provides an assessment of drought severity which meets these requirements.

The use of a GIS makes for convenient display of the spatial extent and severity of a current drought together with other spatially significant information, such as magisterial district boundaries. Furthermore the GIS/modelling system permits both delimitation of drought stricken areas and indication of the intensity of the drought. The system is dynamic in the sense of providing regular updates of a drought situation during the current season. The use of different surrogate scenarios for completing the season will provide valuable decision support for planners and policy makers.

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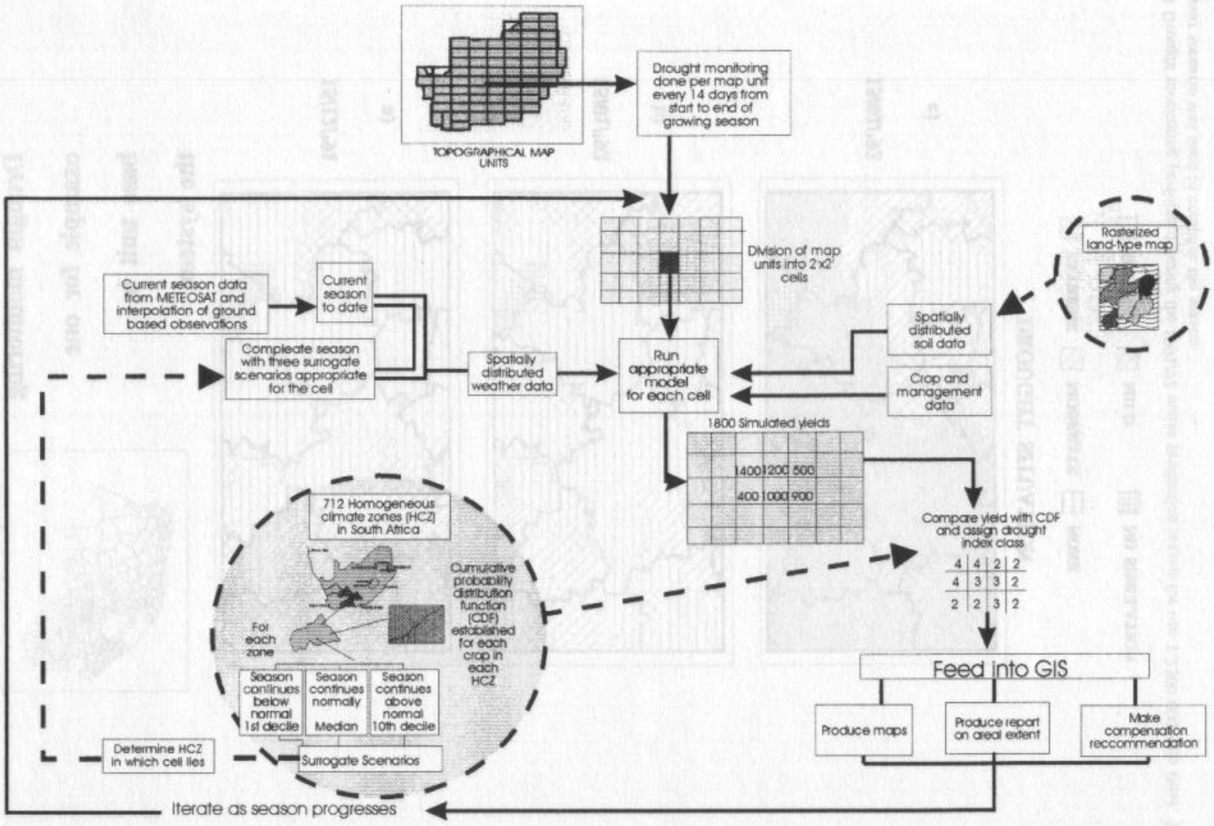

Figure 1 The drought monitoring system

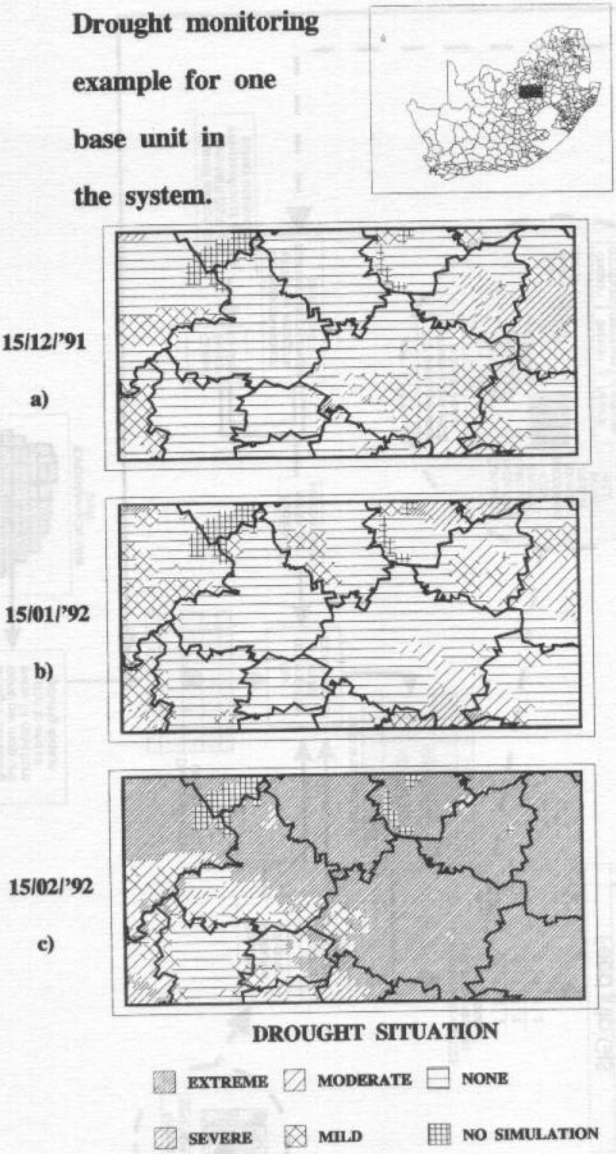

Figure 2 Drought monitoring performed during the 1991/92 maize production season for one 1:2500 000 map sheet. The median rainfall year scenario was used to complete the season.

GEOGRAPHIC INFORMATION SYSTEM FOR THE MANAGEMENT OF INDUSTRIAL RISKS AT THE SUBREGIONAL SCALE

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KEYWORDS

Risk analysis, Geographical Information System, subregional scale, simulation planning, prevention

ABSTRACT

Risk assessment and environmental issues are among the most important subjects of research today.

The dynamics between atmospheric and hydrologic systems imply that all datas in an environmental system can be spatially interrelated.

Thus, an information system can be used as a decision support tool in risk prevention and planning for industrial activities.

The innovative aspects of the proposed project can be summarized in two main approaches:

-Risk evaluation based on an intersystem analysis

-Integrated knowledge of an industrial risk at the subregional scale.

In an evaluation process, all sources, vectors and receptors are taken into account in order to achieve a description of territorial risk (infrastructural networks, transportation of hazardous materials etc...) factors influencing the general evaluation framework.

This validated integrated information system allows evaluations of the possible consequences of industrial disasters or spills regarding:

-new plants and installations, relocation of existing production activities

-infrastructural modifications

-general planning activities,

by using specific models.

The system which can be developed from this project would supply information services at several levels:

-to authorities charged with the control and the management of industrial risk

-to managers of hazardous industries

-the information to the population.

This work takes place in a European Contract (DG XII,n°EV5V-CT920095) with M. G.Giannandrea as scientific coordinator from the Consorzio Venezia Disinquinamento.

INTRODUCTION

The objective of this project is to manage industrial risks at the subregional level. The used tool will be a Geographical Information System (G.I.S.).

Its definition is still a subject of debate (Kineman *et al* 1991) (Klark D.M. , Ruttenberg S. 1992) .

GIS can be described as a combination of several functionalities such as remote sensing,

computer cartography, database management and computer aided design (Maguire D.J. et al 1991).
The innovative aspects of this project can be detailed in two points:

-Integrated knowledge of an industrial risk at the subregional level.

-Risk evaluation based on an intersystem analysis using models.

GIS databases contain information on location, spatial distribution and spatial relationships while environmental models work on a basic currency of mass and energy transfer.
In the last ten years, considerable progresses have been made in integrating spatial information systems and mathematical models of the environment (Karen K. Kemp 1993).
This project intends to define specific criteria in order to create an information system for risk assessment. It will be considered as a decision support tool in a prevention concept.

This workshop is divided into several parts:
-Law analysis of three European countries (France, Italy and Spain). This work is connected with the definition of real users of the proposed tool.
-Definition of the territorial database (definition of parameters for territorial systems and their relation to each other, in order to achieve a systemic knowledge of the territory as a guide to global risk evaluation)
-Elaboration of a database of hazardous industrial plants
(individualization of all information useful for a complete description of an industry as a risk source)
-Database of transportation of hazardous goods (for example, parameters defining the flow of hazardous substances)
-Modelization (description and validation of existing models for accident simulation and evaluation of consequences concerning risks in fixed plants and during transportation).

DESCRIPTION OF THE FRAMEWORK

-Definition of the territorial database (definition of parameters for territorial systems and their relation to each other, in order to achieve a systemic knowledge of the territory as a guide to global risk evaluation)

We detailed a comparison between French, Italian and Spain régulation on risk management in table 1.
For the French part, the territorial database will be the DB TOPO from the Institut Geographique National (I.G.N.) at the scale of 1/25000. Other informations are individualized and will be taken in account: sub-soil, meteorology, land cover, public dwellings etc...

For other European countries, it will depend on the availability degree and the developpment of local and cartographic information.

-Elaboration of a database of hazardous industrial plants and transportation (individualization of all information useful for a complete description of an industry as a risk source , and parameters defining the flow of hazardous substances)

This database aims to define industrial plants in the studied region .
In each country, the information must be extracted from safety reports because they contain enough technical information to guarantee the exhaustive check of safety problem.
The suggested methodology can be understood as a utility to the end user to implement the information of the hazardous plants in the database on the bases of safety reports.
This database definition is made up from geographical objects and organized by themes and objects.
Themes are:
-Safety report classification
-Industrial area or pole information
-Plant information
-Raw materials, products, subproducts
-Storage plants
This theme aims to collect information about the storage conditions in terms of the following aspects:
  *Quantity
  *Tank characteristics and geometry
  *Storage conditions
  *Storage safety tools
  *Features of the containment basins

-Pipelines

The present theme identifies features of the eventual pipeline network (Nature function and quantity of the transported substances, pumping conditions, pipeline, interruption points

-Carriage by tanker truck

The objective of this theme is to identify the flow-rate of dangerous substances inside and outside the considered plant.

-Main accident scenarios

The objective of safety reports in the French case is to evaluate the adequation of the risk of major accidents and the proposed preventive measures. Informations will be collected about accident scenarios retained.

-Intervention

The aim of this theme is to define the availbility of intervention tools and means in case of accident

*Emergency alarms
*Prevention systems
*First intervention equipments
*Fire fighting systems
*Gas detection systems
*Organization of the emergency plan
*Mutual aid assistance

-Database of hazardous goods tranportation (for example, parameters defining the flow of hazardous substances

Transport of dangerous goods is directly in relation to the protection of human health, environmmental protection and traffic safety (Luketic 1994) (Vallet B., Giger F. 1991).
The main aim of this part was to draw up the specifications for a database dealing specifically with the transportation of hazardous goods, identifying the actual flow of substances considered as hazardous materials and defining movement relations with other databases.
A geographical approach is essential. The effects of an accidental spillage of a substance is directly related to the topological, hydrological and geological configuration of the zone in question. In this respect, the drainage basin is the most pertinent scale for analysis.
A comparison of the routes used for transportation of hazardous materials with the biophysical environment reveals sensitive areas, especially because of various environmental features which are more or less resistant to the various forms of attack of a dangerous chemical substance.
This work began with a first part dealing with a general study of national and international regulations dealing with of the transportation of hazardous materials.
The second part was to identify existing databases concerning regulations for the transportation of hazardous materials:
It would appear to be very difficult to find one database that contains all the specific regulations for all of the countries involved in the study.
Several databases were studied with the following criteria:

-General features and purposes
-Accesibility
-Structure
-Information on product regulation
-Information on product toxicity and ecotoxicity

The present conclusions concentrates more particularly on the following databases :

-SECURICI
-INFOTANK
-CC-INFO
-ECDIN
-SAFETY
-ECODATA

The third part aims to identify the main administrative partners involved in the transportation of hazardous materials in each specific the region. The study consisted in identifying fields of competence, researching datas concerning the flow of hazardous substances and availability of these datas :

-Firemen (in the subregional scale, for French, one find the CODIS: Centre Operationnel de Défense contre les Incendies et de Secours)
-Administrative inspectors of the Industry, Research and Environment (Authority: Direction Regional de l'Industrie, Recherche et de l'Environnement DRIRE)
-Police force (Gendarmerie)
-Regional public works authority (Direction Regionale de l'Equipement)
-Harbour authority
-Railway autority
-Environment Ministry

-Transport Ministry
The increasing traffic carrying dangerous substances has led industrialists and administrative concerns to require more and more detail on the exact nature of both the substances carried and the flow of traffic for more efficient monitoring of the transport of hazardous materials.
In fact, it appears as impossible to find a structured database with georefenced coordinate concerning the flow of hazardous substances. A few databases design to respond to specific requirements or involving only one form of transport do exist, but their information would be difficultly connected with the G.I.S. project.
In order to obtain precisions concerning several points, or nodes, of the network involving the flow of hazardous goods, we propose to undertake count campaigns in the region of study.

-Modelization (description and validation of existing models for accident simulation and evaluation of consequences concerning risks in fixed plants and during transportation)

The objective of this part is to identify in the litterature models of consequences evaluation in order to integrate them in the system and providing reliable estimates of risks on a territorial basis.
Concerning the specific case of transportation of hazardous goods, the mathematical models "TRANSIT" and "COLLISION" developped by TRR will be included (Romano A. Renau J.M. 1985).
Concerning the risk due to the BLEVE, the model of LIHOU giving the diameter (average value) of the fireball will be taken in account (because of the consistency of its hypothesis) (Lihou D.A., Maund J.K. 1982)(Fulleringer D. 1991).

Concerning analysis calculation of uconfined vapor cloud explosions, the TNT equivalent model has been chosen.

For the specific problem of models for the calculation of neutral gas dispersion, the Pasquill-Gifford model will be included (Pasquill 1962)

Other specific models have been identified, analysed and chosen for calculating the dispersion of underwater release, dispersion of dense gases and poolfires(Casal J.*et al* 1994)

CONCLUSION

Due to the complexity of chemical plants, hazard analysis is commonly carried out using systemic manual methods like Hazard and Operability Studies (HAZOP) wich are, however very labour intensive and for complex plants very time consuming. An alternative approach for the systemic examination and the application of specific expert knowledge to hazard analysis in industrial plants can be achieved by using GIS tools (Göring M.H., Schrecker 1992).

This work is still in progress. Many parameters and much informations concerning regional studies have been collected. The future objective will be the implementation of dispersion models of hazardous substances in the defined G.I.S.
The final tool will provide the enduser with a complete and pragmatic management of the industrial risk at the subregional scale.

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A CONSTRAINT-BASED APPROACH FOR EARTHQUAKE CASUALTY MODELING IN MANUFACTURING SYSTEMS

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KEYWORDS: casualty modeling, constraint-based reasoning, earthquake loss, industrial safety

ABSTRACT

This research project uses a macro-systems approach to earthquake injury estimation and the integration of scenario consequences into an event tree analysis. This approach is based on the constraint satisfaction theory and its associated algorithms. We using this approach to model the effects of earthquakes on safety of manufacturing systems. More specifically, we provide the structure of a decision tree whereby the effects of a number of simultaneous variables can be traced in producing negative safety and health consequences, given the relevant system constraints. The shell uses symbolic reasoning or constraint propagation to show the results of each manipulation of constraints or trade-offs for five sets of variables: Primary Hazards, Secondary Hazards, Shaking Hazards, Behavioral Hazards, and Production Hazards.

INTRODUCTION

The recent earthquakes in Northridge, U.S.A and Kobe, Japan proved that even the most advanced communities in earthquake preparedness are still vulnerable to these large earthquakes. Recent estimates have been only useful in raising the awareness of the communities as to the devastating effects of these events. For instance, it was estimated that a day-time earthquake of magnitude 7.5 would result in up to $32 billion in shaking losses and an estimated 4,000 fatalities along the Newport fault (Litan, Krimgold, Clarkand and khadilkar, 1992). Another more alarming estimate was given by Shah (Science News, 1994) that a magnitude 7 tremor in the Los Angeles basin could result in $125-145 billion in damage and kill 2000 to 5000 people. However , like other earlier estimations, these casualty consequences of earthquakes have been based on assumptions and formulas that may not consider the full context of this large multi-variable problem domain. Moreover, these estimates do not give us a full picture of the interactive nature of the casualty-causing factors in a particular set of structures. For example, the guidelines offered under ATC-13 assumes deaths and injuries are primarily caused by structural failures. But, recent research suggests that some deaths and a significant percentage of injuries are caused by non-structural elements such as building contents.

Additionally, these non-structural elements and building contents appear to take on a more hazardous form in our today's industrial and manufacturing environments. In a strong earthquake in Japan (January 15, 1993, Kushiro-oki, R 7.8) only two persons were killed; one by a falling ceiling light in an office and the second by gas poisoning (EERI, 1993).

This research project uses a macro-systems approach to earthquake injury estimation and the integration of scenario consequences into an event tree analysis. This approach is based on the constraint satisfaction theory and its associated algorithms (see Mackworth, 1987 for survey of these algorithms; Dechter, 1987 for an application to truth-maintenance; Rit,1986 for a temporal event scheduling). The constraint satisfaction framework is a more natural way of interrelating a fairly large number of interactive system variables within a deductive tree structure or model. An earlier development from this model has been validated for an adaptive management information system in a high-technology manufacturing environment. We are now attempting to use this model (and its associated information system) to study the effects of earthquakes on safety of manufacturing systems. More specifically, we provide the structure of a decision tree whereby the effects of a number of simultaneous variables can be traced in producing negative health and safety consequences, given the relevant system constraints.

RESEARCH IMPORTANCE AND OBJECTIVE

Manufacturing systems are highly integrated work operations. For most organizations, the competition to achieve certain market share or even to stay in business depends on small incremental (continuous) improvements in work and organizational systems. Therefore, any interruption in the production operations may negatively impact the long-term profitability of the production system. After a serious catastrophe, BASF Corporation Director of Insurance stated, "Business interruption losses can be a major threat to a company and in the worst cases could lead to bankruptcy for even the biggest of companies." (Bean, 1994)

A major concern in today's manufacturing organizations is the integration of customer demand and supply into the strategic business objectives. Even if the damaged business can maintain a continued supply by virtue of partial operations, the customers may find it necessary to look for secondary sources of supply in case their now-damaged primary supplier fail. If supply is interrupted, these customers must go elsewhere immediately, and their orders may be difficult to regain. Generally speaking, the business losses due to the human infrastructure may have roots in the following categories:

- Loss of employees (injury, death) and their skills.
- Increase in unemployment compensation premiums and potentially expensive legal actions against the company.
- Increase in cost of training new and retraining the old employees who have been out of job for a period of time.
- Increase in production errors which result in overall production inefficiency.

Also, there may be up to three times more costs labeled as "hidden" or "indirect" costs which the current accounting systems are not able to track (Capettini, 1994).

In Southern California, operations managers are mostly concerned about the devastating effects of earthquakes on their business operations. Earthquake recovery planning has become an important component in many company policies for identifying essential needs, authority delegation and damage case scenario analysis (Lichterman, 1985). Our research is designed to provide a pre-earthquake qualitative damage and injury analysis tool for emergency and disaster managers. The initial development of this tool will be limited to providing qualitative estimates of employee injury and death in a manufacturing system.

THEORETICAL FRAMEWORK

Today's manufacturing organizations are faced with a challenge in their efforts to prepare for natural or man-made disasters. The cross-functionality of a large number of the variables affected by a disaster is complex and poses theoretical as well as computational challenges for manufacturing managers decision-making process.

Artificial Intelligence has found numerous applications in supporting decision-making in organizations, but few in managing the complex issues related to disaster impact assessment and emergency management. The problem of capturing and managing this complexity requires computational structures similar to process design in multi-layer dynamic system behavior. In this effort we are proposing to build upon a computational design framework which encompasses the design of human-related as well as other system components variables in a highly-integrated human-technology organizations (HITOP, see Gasser, et al, 1993). This framework is based upon a decision support system which helps managers to analyze changes in their current operations for adequacy of integration among technology, organization, and people issues, as well as to identify new design choices. A newer development of this shell called ACTION is designed for users to become change agents in manufacturing design decisions (Hulthage, 1994).

CONSTRAINT-BASED MODELING PROCESS

The earthquake injury evaluation problem is specified as a set of constraints to be satisfied (e.g. high-pressure steam generators must satisfy pressure relief mechanisms) and a set of objectives to be optimized (e.g. possibility of steam line ruptures after an earthquake). In this model, evaluation uses constraint propagation to generate values for important evaluation properties of a manufacturing operation captured by the ACTION shell. In this model, ACTION helps an evaluator to relax constraints for an overconstrained problem set and to add constraints to an underconstrained problem set. In such an evaluation procedure, the evaluator can add constraints, make choices based on preferences or to make arbitrary choices until all but one choice remains. The shell uses symbolic reasoning or constraint propagation to show the results of each manipulation of constraints or trade-offs between objectives. To simplify the process, each domain concept (e.g. variable) is associated with a set of constraints that have a subset of qualitative range of values (e.g. low, medium, high) that are deemed appropriate for that concept's definition. Therefore, any change in the constraints on one concept could constrain values on other concepts. This approach employs an algorithm that follows chains of dependencies in order to make all necessary updates introduced as a consequence of new constraints. This approach is different from ordinary constraint satisfaction algorithms in that constraints are changed monotonically toward narrower and narrower constraints, producing a linear complexity for tree our tree-shaped constraint network. If the tree contains any cycles, a supplementary algorithm will be used to manage the time and space limitations.

MODEL ARCHITECTURE FOR CASUALTY ESTIMATION

The current architecture represents a set of objectives (goals) to be optimized and a set of detailed, hierarchical constraints based on the theory mini-models, that describe how to optimize for these objectives. At this point in time, we are developing a detailed constraint model of the possibility of achieving one objective: minimizing employee injury and death. We have a large number of constraints, trade-offs, and value assignments for five sets of variables (concept domains) that form the theory mini-models. These five sets of variables are: Primary Hazards, Secondary Hazards, Shaking Hazards, Behavioral Hazards, and Production Hazards (Figure 1).

Mini-models define a constraint network in terms of domain concepts and their relations. The top (root) of each of these mini-models is an organizational objective (e.g. minimize production hazards or minimize primary structural collapse) and the bottom of each is determined by input data from theory or user constraints. As can be seen from Figure 1, our mini-models are approximately tree-shaped.

The earthquake casualty model in a manufacturing environment can be large and complex. To limit the size and complexity, the constraints within the mini-models are viewed as (a) constraint among variable values or arguments ("e.g." if earthquake resistance design is <inadequate>, then the severity of injuries is more than <minor>, (b) desired level of correlation between variable values ("e.g." if MMI is <large> and shaking duration is <larger>, then the shaking effect is <significant>), or (c) desired level of congruence (qualitative match) among variable values ("e.g." we place a check mark or a color code in a relational table containing variables and their associated values representing all the feasible combinations: red, green, and blue signify negative, positive, and neutral influences). Then this approach becomes one of searching through the possible value assignments to variables for acceptable, highly-evaluated process.

Each of the five domain specific problem space is further related to a number of variable sets, and so on (only the Production Hazard branch is explored in this paper). To show the preceding variable set relationships for the Production Hazards, four sets are presented on Figure 2. Factors which influence the work environment itself may include hazardous material dispersions, distribution of airborne particulates (e.g. dusts), release of substances with high temperatures, etc. Two factors are assigned to the ability of equipment to resist earthquakes: resistivity of large integrated machining centers (e.g. CNC) and smaller manufacturing equipment. Energy distribution systems are another source of occupational hazards which may involve maintenance quality of the system, appropriate design of natural gas systems, and design of electrical systems with respect to earthquake shaking disturbances. The fourth factor in this node is the shaking resistance of the material handling systems which may include programmed robots and associated tools, instability of conveying mechanisms, maintenance quality, and size and weight of objects being handled. Now, as expected, each one of these variables are further influenced by a number of other variables which comprise the entire tree-shaped model (not shown here).

A first version of the model has been developed using variables identified from earthquake casualty literature. A test version of the software is being simultaneously written to obtain preliminary computational requirements. The next step will be to collect data through an on-site examination of an industrial facility damaged by a recent earthquake. A generic questionnaire set has been developed to obtain detailed information on each model variable. The questionnaire is designed to produce response sets that match the variable set qualitative range of values (e.g. low, medium, high) which can be easily used as inputs to the shell. Also, the design of the questionnaire allows for responses by any employee who has knowledge about the operational facility before and after the earthquake. Further developments are subject to additional research funding.

CONCLUSION

The proposed model is designed to identify potential hazard areas and procedures during an earthquake as well as predicting casualties and potential capital losses due to equipment or structural damage to manufacturing systems.The system can also be used to aid the emergency managers, concerned with earthquake casualties, in pre-accident analysis and post accident investigation.

The impetus behind this development effort is the lack of casualty estimation software in work-related settings. Also, traditional earthquake loss estimation methodologies have mostly taken into account the physical damages from shaking forces. There is a need for methods that estimate the human casualties with reference to specific structural settings. A major advantage of this approach is that the system does not require quantitative data (e.g. variables, arguments, algorithms), exclusively. The other advantage of this system is its flexible mini-models which can be added or deleted throughout its validation process.

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BIOGRAPHY

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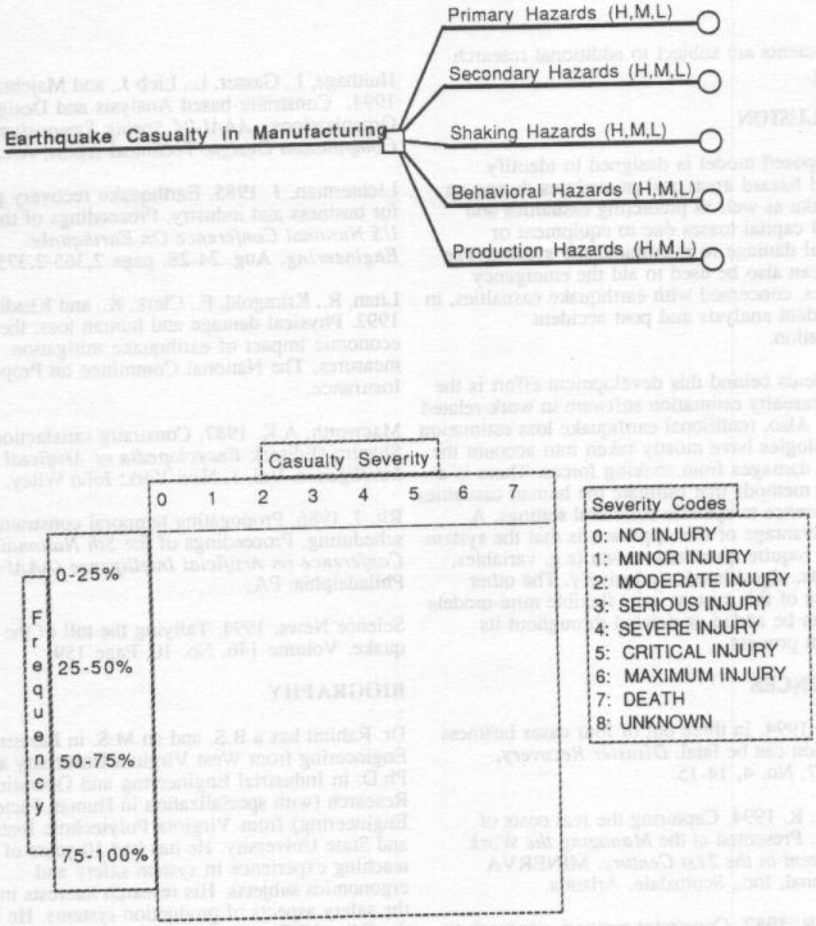

FIGURE 1. The first node for the constraint-based tree model incorporates five major hazards in a manufacturing system due to an earthquake. Each hazard is constrained (to the casualty consequence) by a two dimensional severity versus frequency table.

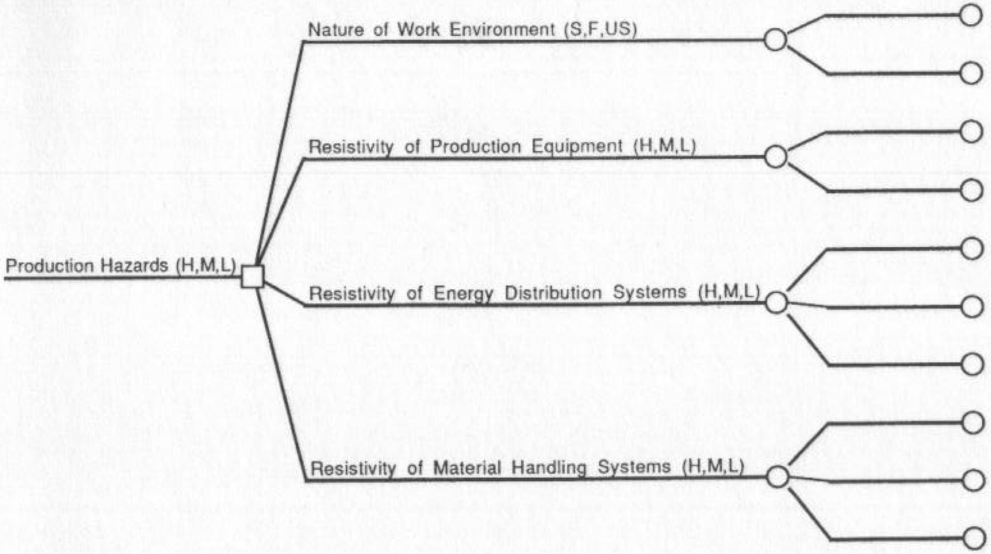

FIGURE 2. The Production Hazards node is expanded to include a number of variables in its domain. Each node expands to a number of other branches to contain all system variables identified as important in the model validation phase.

TIEMEC '95

Research and System Development

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BUILDING AN EMERGENCY MANAGEMENT APPLICATION AS A PROCESS DRIVEN TOOL COOPERATION

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KEYWORDS: Emergency Management, Tool Integration, Workflow, Information Access

ABSTRACT

Building an Emergency Management Information System (EMIS) should be guided with at least the following requirements: providing the emergency managers (EMers) with the best services for managing the crisis situations, and especially a direct access to the information needed to act and take decisions; providing a system that is not a proprietary one but a combination of "Of The Shelf" products that work together in an efficient way; providing help and guidance to the end-user in using the system and navigating through it.

The integration of several tools together in order to build a final application should be done along four axes : data integration, control integration, presentation integration and process integration. In order to fulfill these requirements and to cover the four aspects of integration, we propose to use a Broadcast Message Server approach to define an integration framework and a Process Model approach to ease the navigation in the system.

REQUIREMENTS FOR AN EMERGENCY MANAGEMENT INFORMATION SYSTEM

An Emergency Management Information System (EMIS) that is well adapted to Emergency Managers's needs (EMers) should fulfill the following requirements:

- provide a well integrated set of services ranging from communicating with people, through evaluating a current situation and predicting the evolution of a problem, to following the activation of a contingency plan;
- easy maintenance where the replacement or the addition of functionalities is done without great modifications of the system;
- inclusion in the EMIS of existing systems: usage of a specific Geographic Information System (GIS) and its cartographic database, access to a chemical database, dedicated communication tool.
- inclusion in the EMIS of some Commercial Off The Shelf (COTS) products which are well suited to provide a subset of the EMIS functionalities : GIS, document editor, mailing tool;
- provide a support for the end-user to navigate in the EMIS set of functionalities to help him in his decision making process.

In order to take into account all the previously stated requirements in the development of an EMIS, we present in this paper the benefit of viewing the system as a tools-cooperation environment where a process driven approach provides great added value. After having described the system we have developed for a flood application in the French Alps, the technical solutions we have adopted are presented.

FLOOD MANAGEMENT IN THE FRENCH ALPS

The **MEM*brain*** project [1] facilitates the development of EMIS by providing ready-to-use services for crisis management and an integration plateform to build final applications. Within the project, CAP GEMINI INNOVATION is in charge of providing this integration plateform. We are also working on an application dealing with flood management.

In the **French Alps of Savoie** near the city of **Chambery** there exists a flood risk of the **Leysse** river. This risk is due to the proximity of mountains, and of sudden thaw of snow on the ground which, when combined with rain, creates floods.

This paper focuses on the services available for crisis management. These services are dedicated to the Chambery flood EMers. In order to make these services easier to understand, we present them in a potential flood scenario.

Within this flood scenario, support is provided for the following user's actions :

- **consultation of historical floods**: this provides cartographic views, diagrams and textual description of past floods.
- **evaluation of the risk**: the end-user indicates the risk level of a potential flood to the system (we have

classified the risk as "normal", "alarm", "alert", and "crisis"). According to this risk level the system identifies a set of actions to be performed.

- **monitoring sensors**: this provides him with real-time diagrams of the sensor data and the sensors localization on the map.
- **simulation of the flood**: this provides him with a step by step simulation of the flood evolution on cartographic views.
- **activation of a contingency plan**: the end-user can activate actions with a "check list" mechanism attached to each action in the plan.
- **annotation of the map with an incident**: this allows the end-user to follow the evolution of the situation directly annotating a map.
- **definition of snapshots of the crisis**: with a simple click on the corresponding service, the current screen image is stored in the system log.

In the presentation of the technical solutions adopted to build this system, some specific points of the system will be highlighted and described more deeply.

INTEGRATION

A classic software development life cycle is divided into several phases : a requirement phase, a design phase, a coding phase and so on. In our approach we propose to replace as much as possible the coding phase by an *integration phase* consisting of the integration of existing pieces of code like COTS products. The EMIS then becomes a well adapted "mix-and-match" of existing components.

The integration of several software components, in order to be comprehensive, must be considered along four axes :

Data integration Data integration is concerned with the data sharing (i.e. when two different components share the same data). When a product directly uses the data produced by another, there is a natural continuity and no loss of information caused by the translation of the data.

Control integration Control integration is concerned with the operation sharing, when one component is able to call an operation implemented by another component. This gives to the end-user the feeling that he is in front of one unique set of operations without knowing which product implements which operation.

Presentation integration Presentation integration is concerned with the fact that all the products which compose the application present the same look and feel.

Process integration Process integration is concerned with the sequencing of the operations may be implemented by different components. This sequencing is modeled outside the component in reference to a process which describes the end-user way of working.

Because we need to provide an environment which is comfortable and effective for the emergency manager, we have to define an architecture which addresses **all** these aspects:

- **data** : same data are shared in different components (i.e. when a document treats a specific building we want to be able to show it on the map)
- **control** : the operation of a specific component can be directly executed from a different component (i.e. when we are on the geographical view we want to be able to see the preparedness plan attached to this sensitive site)
- **presentation** : views and operations from different components have to be displayed on the same screen and so accessing them should be done in a consistent way, ergonomic rules are therefore preponderant in the environment (i.e. each component operation label is displayed with the same font and color and accessible in the same manner)
- **process** : the same component can be used for running different processes and provide many operations, so we want for the end-user a short and easy way to execute well defined processes (i.e. we want for all operations consultating past floods to be directly accessible when needed with no need to find the operation in the sub-menus of the GIS and EDITOR components)

Architecture

The architecture underlying our system addresses all these aspects of integration (data, control, presentation and process). For each we will present the baseline technology which supports it.

The architecture of the system is designed around an *integration platform* where components are *plugged in*.

Most of the functional components needed for the application already exist in the market. For example, there is in our application a GIS component which displays geo-referenced objects on a map, and an EDITOR component for document management. The architecture of the system is a collection of such component tools. A tool is : "*runtime software which manages its own user interface (displays views and provides end-user operations)*". Some tools are products available on the market and some tools are specially developed in order to provide a novel set of functionalities.

An application is defined as "*a set of tools cooperating by providing services to each other in order to achieve end-user functionalities*".

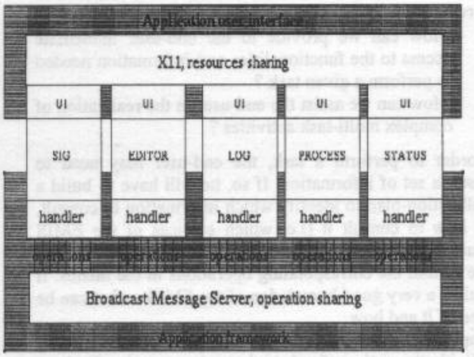


Figure 1: Architecture

In order to develop an application it is needed to build an integration framework which enables these tools to communicate between them. This integration framework defines an abstraction of each component in terms of the operations a tool-component is able to provide to another component. Then the total application is seen as a set of components, some being clients and some servers. Our integration will consist of establishing the relations between the clients and the servers. This aspect will be described in the BMS section.

This architecture allows the definition of the application through the *composition of customizable, ready-to-use bricks*. We have an easy assemblable set of components and an integration framework.

Building a new application will consist of choosing the right components according to the operations set required and then plugging the components into the integration framework.

The visible user-operations and how these operations should appear (in which view or menu of which component) may imply interaction between different components. Data exchange between components or the calling of one component from other one constitute the customization phase of the integration of the components into the framework.

As such, an open architecture is very important for our environment where the integration of a new component or the replacement of one by another has to be done easily. Managing the crisis is a complex mechanism where big volumes of information have to be taken into account but where the procedures are not fully defined nor is the information to be managed fully grasped. So an *iterative* approach should be used for building the system. And our architecture can be of great help with this approach where the integration into the environment of new components is done without a big reorganization of the total system.

Broadcast Message Server

The Broadcast Message Server (BMS) is a software developed by Cap Gemini Innovation for enabling the communication between several different tools. Originally it implements the *integration by control* which has been discussed in the Integration section (allowing a tool to call an operation implemented by another tool). We have also used the BMS for data integration. In fact we do not address data sharing but implement instead data exchange mechanism. No great volume of data being shared by different tools, tools exchange the data on explicit request instead of sharing the same database. Thus the two aspects of the integration are implemented by a single mechanism. This mechanism is supported by the BMS.

Originally the BMS is a common service for the broadcasting of messages between different tools located on a local network. There are two different types of messages, the **"request"** and the **"notification"**. A tool is able to receive a message when it has defined a filter which matches the broadcasted message. A message is composed of fields identifying an operation and the tool which provides it.

For example the EDITOR requests the GIS to display on the map the most exposed flood areas. The C code for this is :

```
SendMessage("R","GIS","DISPLAY_AREA","*","FLOO
D_EXPOSURE")
```

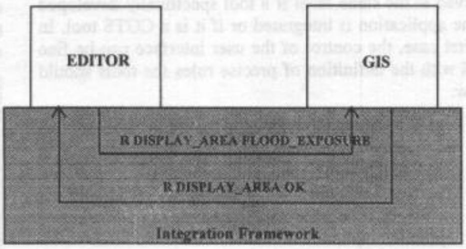


Figure 2: BMS messages

The callbacks define by the GIS server to the operation DISPLAY_AREA will be started on the reception of the message. And the GIS will notify the execution by sending a notification message with the return code in the data field.

All the "plugged" tools have to identify the operations they want to provide to others. The BMS then provides a mechanism which allows all the tools to request a query and get the result.

In order to provide an architecture which is as open as possible and to allow the interchangeability of the tools, the format of the exchanged data (like **FLOOD_EXPOSURE** in the example) is independent of the tools which are communicating them. Thus *it is* *possible to replace a tool by another one implementing the same functionalities without any effect on the rest of the environment.*

The BMS defines an architecture where the tool does not appear directly as such. The only declared entities are a set of classes (like **GIS** in the example) which provide a set of operations (like **DISPLAY_AREA** in the example). When a tool wants to communicate information with another one, the only thing it has to know is the format of the message to be exchanged. The BMS delivers the message to the tool which provides the operation for its execution.

The integration of market product is done by the definition of a *handler* which presents the tools' BMS interface to the integration framework. The role of the handler is to translate the BMS operation into the internal language of the product. Depending on the openness of the product (most of the market products offer the ability to communicate through RPC, SIGNAL, SOCKET and so on) the technique for their integration will be different and the product will be integrated in more or less fine-grained manner.

USER INTERFACE INTEGRATION

Integrating several tools may be badly perceived if the resulting user interface of the application is not consistent. Indeed the end-user should not have the feeling of several tools running concurrently. The application should have a consistent look and feel. This consistency cannot be achieved at the same level if a tool specifically developed for the application is integrated or if it is a COTS tool. In the first case, the control of the user interface can be fine tuned with the definition of precise rules the tools should follow:

- for the presentation: like the font to be used in push button, the position of the "help" push button in a window ...;
- for the behavior: like a confirmation should be asked of the end-user before any destructive operation ...;
- for the customization at integration time: like changing the language, the color of the background of the windows ...

Concerning COTS tools the adaptation of their user interface is dependent on tool flexibility. Nevertheless, it is almost always possible to influence the size and position of the windows as well as some general attributes like background color. These minimal adaptations will ensure a correct level of integration since they will reduce the differences that exist between the tools.

PROCESS INTEGRATION

The functionalities dedicated to crisis management are unlikely to be very familiar to the end-user since they are not used very often. At the same time, as crisis situations are very stressing the system should be as easy to use as possible. For this reason, we have tried to find solutions to the two following points :

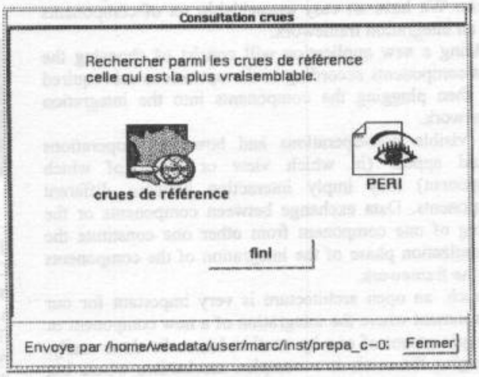
- How can we provide to the end-user immediate access to the functionalities and information needed to perform a given task ?
- How can we assist the end-user in the realization of complex multi-task activities ?

In order to perform a task, the end-user may need to consult a set of information. If so, he will have to build a small action-plan to identify which information to consult, and how to consult it (i.e. which services of the EMIS should he activate). Once this action plan is ready he will have to find the corresponding operations in the menus. It requires a very good knowledge of the EMIS : what can be asked of it and how.

Symplifying the system use is achieved by introducing explicitly the notion of task to the end-user under the form of a **"Work Context"**. A work-context contains:

- a textual description of the task itself,
- the needed information to be consulted and the way to consult it,
- the result to be produced if any.

Let us see an example taken from our system. When the end-user receives the alarm message announcing a meteorological problem, his task will consist of answering the question : what kind of flood can be expected ? In order to do so, he will activate the task : "Consult floods" (Consultation crues). This task is presented as a work context (see "Consult historical floods task" figure).



Rechercher parmi les crues de référence celle qui est la plus vraisemblable.

Envoye par /home/weadata/user/marc/inst/prepa_c-0:

Figure 3: Consult Historical Floods Task

The purpose of the task is described and the needed information is proposed : the historical floods (*crues de reference*) in a cartographic form and the document (*PERI*) in which a textual description of them is provided.

In order to access this information, the user will simply click on the corresponding icon.

As we can see the way to access to the information is task-driven and therefore very natural for the end-user. He does not have to know which computer function to activate and how to go about it.

This provides an answer to the first requirement "*How can we provide to the end-user an immediate access to the functionalities and information needed to perform a given task ?*".

For the next point "*How can we assist the end-user in the realization of complex multi-task activities* ?", the problem is that in crisis management the EMers have many activities to managed in parallel and it can become quickly very difficult to control all these activities and to know what is going on and what is to be done next. In order to help them in their job, we have added two more elements to the EMIS:

- a list of the on-going tasks in an Agenda window;
- a process support to decide which new tasks need to be carried out.

The Agenda (see figure 4) is a graphical representation of the list of tasks to be done. A task which is in the agenda is "on", that is to say that the end-user has activated this task but it is not finished yet. When clicking on the task icon, the corresponding work context is displayed.

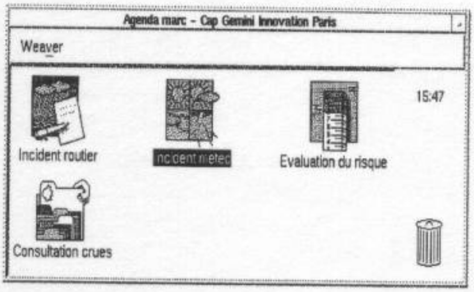


Figure 4: Agenda

When the task is finished, it is removed from the Agenda. Having the list of tasks to be done always at hand allows the EMers to have a clear view of the situation. It is then up to them to decide which task is to be activated next. This is very important since it allows the end-user to switch from one task to another. He is not obliged to finish one task to start another. Thus, the end-user is able to delay some tasks (without abandoning them) to face the emergency.

In crisis management, there are some "reflexive activities". Such activities are activated in **known circumstances** by the end-user (after a given event has occurred for instance) or by the system itself (in case of periodic activities). The main feature of such an activity is that the sequencing of the tasks involved in it is well known.

In order to free the EMers of having a precise knowledge of these activities, the EMIS can act as a secretary reminding periodic tasks to the end-user and ensuring that all tasks of an activity are carried out.

To do this a **Process Model** approach has been used. We propose to model the reflexive activities as procedures and then to execute the procedures. This has been done using the **Process Weaver** tool which allows to model the procedures graphically through a Petri Net formalism. It also supports the definition of the work contexts previously described and the Agenda. The **Process weaver** tool supports the execution of the procedure by putting new tasks in the Agenda as described in the procedure model.

For instance, in the system a reflexive activity called **Flood preparation** has been implemented. This activity, which is activated by the end-user when a meteorological problem is announced, consists of :

- putting in the Agenda the **Consult floods** task;
- then putting in the Agenda the **Evaluate risk** task;
- then if the risk level has been set to "*alarm*" putting in the Agenda the two new tasks :
    1. "*Send an alarm message to the corresponding authority*"
    2. "*Sensors monitoring*".

The advantage of this solution is that the system is not too constraining. Once a task is in the Agenda it is the end-user's decision to decide to perform it or not.

We must be very careful when using this kind of approach for a crisis management system. Not ALL activities need to be or can be modeled as procedures.

Process integration is interesting for EMIS for two reasons :

1. in the development of an EMIS this can be done progressively : once the needed functionalities of the EMIS are implemented a "*process level*" can be added to ease the EMers's job;
2. it provides great help to the user in navigating in the EMIS.

CONCLUSION

As we have seen throughout this paper, building an emergency management application as a process driven tool cooperation is a profitable approach for at least three reasons :

- putting user's needs before technical constraints : what services are really needed ? How can he use them in the best way ? How can he access them in the easiest way ?
- adapting software use to the EMers's natural way of working : tool cooperation allows the definition of systems which are closer to the existing world

and the natural way of working (the very computer aspect of the system is not made so evident).

- reduction of development time since it gives a greater importance to the reuse of existing up to date software.

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USING A GROUP SUPPORT SYSTEM TO RE-ENGINEER THE DISASTER DAMAGE ASSESSMENT PROCESS

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ABSTRACT

The American Red Cross establishes a temporary relief organization that may consist of thousands of people and may spend hundreds of millions of dollars to provide disaster relief services following a major disaster. The effective and efficient mobilization of resources and delivery of services requires that the Red Cross has the capability to determine what services are required and where they are needed. This paper describes a recent workshop of Red Cross disaster experts and the use of a Group Support System (GSS) to facilitate the re-examination of the organization's disaster related information needs and the re-engineering its damage assessment process. The twenty workshop participants identified data object classes and data attributes, provided a preliminary data architecture, and prioritized information needs. The successful use of the GSS demonstrates that technology is useful for more than collecting, processing, and distributing information. The GSS provides valuable tools for determining what information is critical to disaster managers, why it is required, and when and where it is needed.

INTRODUCTION

The American Red Cross and other response organizations must, in order to mobilize appropriate resources and deliver effective services, quickly obtain a useful understanding of the problems and demands created by a disaster. We deliberately selected utility as the criteria for evaluating the information picture that must be created for these responders. Terms more descriptive of data quality obscure the fact that utility is the only true test for information during a crisis. Crisis response is obviously time constrained and trade offs must be made between the four criteria of data quality: accuracy (is the data correct?), completeness (are critical data missing?), consistency (are conflicting values reported?) and timeliness (does the data reflect current conditions?). The American Red Cross, recognizing that their ability to obtain useful disaster information is a key to improving their response capability, has initiated a major re-design of its damage assessment process.

Improved use of information technology will obviously be a key part of the Red Cross damage assessment initiative. When information technology is proposed as a means for improving the process of assessing damage after a disaster, the focus is usually on the HOW of damage assessment. How we obtain, process, and transmit information is certainly critical and is obviously amenable to improvement through the appropriate application of information technology. This paper, however, describes an innovative use of group support technology to determine WHAT information is required, and WHY disaster response managers require it. Only when we have clear answers to these questions can we set the priorities that will enable us to select the best technologies for collecting, processing, and transmitting information. Too often, crisis decision making is based on information that is available or is trusted rather than on information that is required. In order to improve the quality of information, we must first ensure that the design of the damage assessment process is driven by response needs, not by the availability of data.

A recent workshop of 20 American Red Cross disaster managers was convened by the national Red Cross to begin the process of re-engineering that organization's damage assessment process and procedures. The authors facilitated the workshop in the George Washington University Management Decision Center, an electronic meeting room environment. Group decision and process support tools were provided by the Group Support System (GSS) software GROUPSYSTEMS V, developed by Ventana Corporation. The results of the meeting provide a critical first step in the improvement of the Red Cross damage assessment function.

BACKGROUND

The objective of Red Cross disaster services is to provide prompt, effective services that meet disaster caused basic human needs and to assist disaster victims to begin and complete their disaster recovery efforts (ARC, 1991). These services include both emergency mass care services and assistance to individuals. The role of the American Red Cross in disaster response was established by Congressional Charter and was re-affirmed in 1988 by the Stafford Disaster Relief and Emergency Assistance Act (PL 93-288 as amended). The American Red Cross is the only non federal agency included as a lead agency in the U.S. Federal Response Plan and has been assigned lead responsibility for Emergency Support Function (ESF) Six, Mass Care (FEMA, 1992). When a disaster occurs, the American Red Cross establishes a disaster relief operation organized along functional lines. There are four direct service functions:

- *Mass Care:* The provision of emergency shelter and feeding to disaster victims
- *Family Service:* The provision of financial assistance to individuals and families
- *Disaster Health:* The provision of health services to victims and disaster workers
- *Disaster Welfare Inquiry*: The provision of information regarding the location and status of disaster victims

These direct service functions are supported by eight internal support service functions, seven external support services, and the overall administration and management of the operation. For a major disaster operation, this organization is staffed by and reports to ARC Disaster Services management in Washington, D.C. It coordinates its activities with the Federal Disaster Field Office through its ESF 6 staff and other liaison mechanisms.

THE DAMAGE ASSESSMENT WORKSHOP

Planning for rare events such as disasters is a difficult task for organizations and managers. Organizational knowledge is fragmented; managers must elicit, reconcile, and integrate the partial knowledge of experts who have experienced different events under different circumstances. Belardo and Harrald (1992) first conceptualized the application of Group Support System tools to this problem domain. They emphasized the need for the support of divergent thinking as described recently by Gallup and Cooper (1993) and Dennis and Valacich (1993), as well as the need to facilitate group convergence and the integration of ideas. Alharthi (1993) tested these concepts with a controlled experiment involving Red Cross planners and found that the facilitated GSS meetings did, in fact, produce outcomes superior to the normal Red Cross planning process.

Based on this experience, the George Washington University proposed, and the Red Cross accepted, the use of a Group Support System environment to initiate the re-engineering of the disaster damage assessment process. The Red Cross assembled 20 of their most experienced disaster relief functional managers at the GWU Management Decision Center on November 7, 1994. The objective of the meeting was to identify the performance requirements and conditions of satisfaction for the information and reports generated by the Red Cross Damage Assessment function; the participants were experts from other Red Cross functions, the primary users of this information. The workshop was conducted as a facilitated, scenario driven, set of exercises. The initial scenario described a major disaster and the exercises were driven by questions posed by the facilitator. The exercises were designed to move the group through a process that (1) identified the demands that the disaster would place on the Red Cross, (2) identified the information required to support functional managers efforts to meet these demands, (3) structured these information requirements, and (4) prioritized these requirements.

EXERCISE RESULTS

The first exercise was intended to identify the key tasks for which must be supported by information generated by the damage assessment process. The GSS Topic Commentator tool was used to provide each participant with a set of electronic folders representing the Red Cross 4 direct service (*mass care, family service, health services*, and *disaster welfare inquiry*) and 9 support functions. They were then asked to identify the most important tasks that must be done for each function during the first week of the disaster response. The participants generated 265 task statements, evenly allocated between the direct service functions (101) and support functions (100). They identified 21 tasks for the relief operation director and administrators and 100 tasks for the relief operation support functions. The four headquarters elements accounted for another 30 tasks and 13 tasks were identified for external organizations. The results from this exercise provided the basis for the determination of information requirements. The task statements generated were a valuable product in and of themselves for Red Cross managers; the task statements provide the raw material for the creation of an enterprise model of the Red Cross disaster relief operation.

Exercise two, the identification and structuring of information needs, was executed in three iterations. In the first iteration, proposed data object classes or categories were generated using the Idea Organizer GSS tool. Participants responded to the question: What information do you need to know to perform the functions and tasks identified in exercise one. Next, the experts were asked to generate amplifying descriptive comments under each proposed category. Finally, the categories were restructured in public session with the aid of the facilitator by combining similar categories and eliminating redundancies. The first iteration produced 74 potential data object classes and 257 amplifying comments or object descriptions. In open session these were collapsed into 15 data object classes. These classes and the number of attribute descriptions provided are shown in table 1. Four interesting observations may be inferred from this table:

1. Much of the information required by the ARC can be gathered before the disaster strikes: demographic information, housing stock description, information about government jurisdictions.
2. The ARC has little use for the initial media reports that stress the death and injury toll. The ARC needs a complete description of the incident, the affected geographic area, and the damage to structures to estimate demand, and infrastructure damage to enable managers to mobilize the relief operation.
3. Knowledge concerning what other response organizations (Federal, State, local, and volunteer) are doing is critical to the ARC, although it is not usually considered disaster assessment information.
4. Two of the critical information areas are derived data; the analysis of secondary hazards and the service delivery analysis must be produced by analysts in the Red Cross or other organizations based on initial damage reports.

The third and final exercise was an evaluation of the priority of information needs. During the prioritization exercise participants were requested to evaluate the importance of each data object class for each function or organizations listed using the rating capabilities of the GSS tool Group Matrix. They were directed to use a scale of 1 to 5 where the rating represented the relative criticality of the data object class for the successful completion of the function's or organization's tasks:

5 = very critical
4 = critical for
3 = important for
2 = useful for
1 = interesting, but not really required

The prioritization exercise yielded three important results:

1. The sum of all the evaluations across all functions and organizations (Group Matrix row totals) gives a ranking of the relative importance of the data object classes.
2. The sum of all the evaluations across all data classes (Group Matrix column totals) gives the relative ranking of the relative importance of information for each function and organization.
3. Comparison of cell entries in the matrix furnish valuable insight into differences in information requirements between functions and organizations.

The prioritization exercise clearly differentiated between the most important and the least important data. Four data object classes were evaluated as critical overall:

INCIDENT DESCRIPTION	4.13
DESCRIPTION OF DAMAGED STRUCTURES	4.08
SERVICE DELIVERY/SUPPORT ANALYSIS	3.98
GEOGRAPHIC AREAS AFFECTED	3.96

This result re-affirms the traditional Red Cross damage assessment process that focuses on obtaining information about damaged structures. Incident description and affected area information, however, are unlikely to come from internal Red Cross sources. The importance of these data identifies a need for the Red Cross to ensure that it has established reliable means of obtaining information from federal, state, and local governments. Service delivery and support analysis are derived data and the importance given to these data indicates that a rapid information processing and analysis capability is very important to the Red Cross operational response.

Only one data object, MEDIA CONTACTS AND ACTIVITIES was rated as less than important (<3.0). Two other data object classes were, however, almost fell below the 3.0 importance score:

MEDIA CONTACTS AND ACTIVITIES	2.79
HOUSING STOCK	3.03
DEATHS AND INJURIES	3.13

Media interest ensures that DEATHS AND INJURIES are the most available data following a disaster. The results of this exercise shows, however, that this data is of limited interest to the Red Cross responders.

The evaluation exercise also showed that Red Cross functions varied widely in their dependence upon information for the successful completion of their assigned tasks. The most information dependent functions were, as shown below, the local and headquarters management of the relief operation and the two primary service delivery functions, *mass care* and *family service*, and *media relations:*

Disaster Relief Operation Administration	4.39
Headquarters Operations	4.27
Family Service	4.16
Media Relations	3.95
Mass Care	3.95

At the other end of the spectrum, damage information was evaluated as less than important to the success of six functions. These functions are all administrative or support in nature; they do not involve providing direct services to victims.

Records and Report	2.11
Disaster Relief Operation staffing	2.68
Building and Repair	2.79
Headquarters staffing	2.83
Supply and Logistics	2.85
Communications	2.94

Examination of the individual cells in the Group Matrix output provides a comparison by function and by information type. This comparison shows that different functions require a different mix of information and that each function has critical information needs. For example, the INFRASTRUCTURE data object class was evaluated as critically important (4.00) to *Supply and Logistics*, even though the function ranked relatively low in its overall dependence on information. Similarly, the DESCRIPTION OF DAMAGED STRUCTURES object class was evaluated as critically important (4.22) to the building and repair function. The DEATHS AND INJURIES object class, although rated as not critical to the operation as a whole, was rated as critical to the *Disaster Health* function (4.71), the *Disaster Welfare Inquiry* function (4.61) and the *Relief Operation Administration* function (4.28). Detailed examination of the prioritization matrix will yield additional insights for Red Cross managers.

The final exercise evaluated the requirement for timeliness of each data object class for each function or organization. Participants were asked to assign an number that represented their assessment of when the data type is required by each function or organization using the following convention:

1 = within one day of the disaster
2 = within two days
3 = within three days
4 = within four days
5 = within five days

It is informative to examine the data classes evaluated as required within the first two days. Three data classes were evaluated as required within 36 hours (mean of <1.5): INCIDENT DESCRIPTION, GEOGRAPHIC AREA, and INFRASTRUCTURE DAMAGE. These represent the information that is most time critical and should be obtained first. Four other data classes were evaluated as required within 48 hours (mean of <2.0): DEMOGRAPHIC INFORMATION, DESCRIPTION OF DAMAGED STRUCTURES, SERVICE DELIVERY ANALYSIS, and LOCAL GOVERNMENT/CHAPTER ACTIVITIES. These represent the information that should be obtained next.

Seven functions were identified that need information within 48 hours: *Administration, Mass Care, Disaster Health Services, Public Affairs, Media Relations, Government Liaison,* and *Family Service*. These represent the functions that should have priority in the ARC information distribution process.

CONCLUSIONS

Three important results were obtained from this one day workshop. The first was a preliminary structure of the Red Cross disaster damage assessment information needs. The second was an evaluation of the relative need for this information measured both in terms of criticality and timeliness, for each Red Cross function. Finally, the utility of GSS as a disaster planning tool was demonstrated.

Figure 1 is a data structure diagram constructed from the results of exercise 2. For clarity in presentation, the data attributes identified during the workshop are not shown. Figure 1 leads to several interesting inferences:

- There are three general clusters of Red Cross information requirements: information about the disaster itself, information about other organization's response to the event, and derived data that is used as the basis for organizational decisions.
- Several critical data classes in the disaster event group are best obtained from information sources outside of the disaster operation. Demographic information and housing stock information can, for example, be maintained for high risk areas prior to an event. Most of the incident description data are obtained from federal government sources, e.g. the National Hurricane Center for Hurricanes, the U.S. Geological Survey for earthquakes.
- The most critical data object classes are all closely linked to knowledge of the area affected. The central nature of this data class is clearly shown in the data structure diagram.
- Information about the activities of other response organizations is required by most Red Cross functions. Obtaining the information is not a formal element of the Red Cross disaster information gathering process.

The results of the prioritization exercises provides important guidance to Red Cross information planners. There is a wide variation in the value of information by data object class across the Red Cross functions. The data object and attribute descriptions produced during the exercises should be refined and a complete data model produced. The function/object matrix analysis should be extended to produce traditional data source--data use matrices. The Red Cross can use this type of analysis to ensure that their revised system gets the right information to the right function at the right time.

An important result of this project was the demonstration of Groups Support System (GSS) technology as an effective and efficient aid to disaster planning. The GSS brainstorming provides a mechanism for extracting the partial expertise of experts. The organizing and prioritizing tools enable a group to organize and integrate its output. This project shows that GSS technology can play a critical role in the design of disaster plans and systems.

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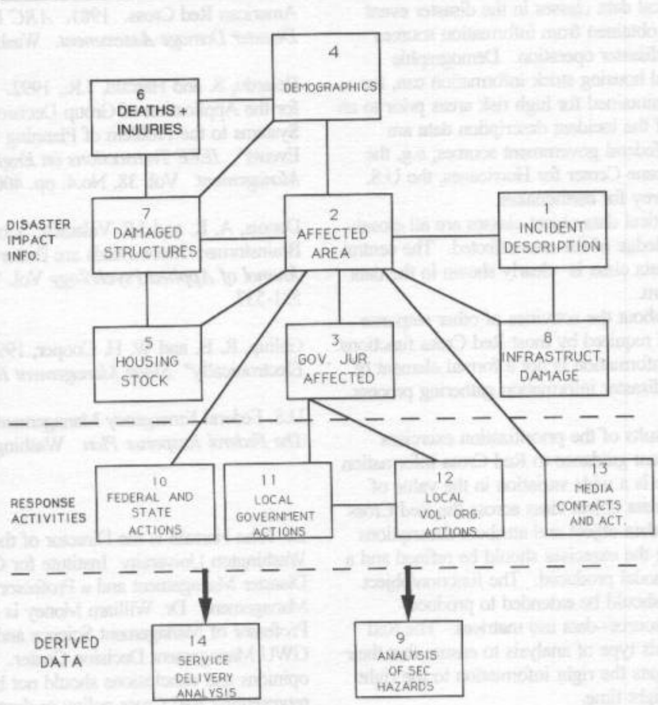
Table 1
DATA OBJECT CLASSES IDENTIFIED

DATA OBJECT CLASS	NUMBER OF ATTRIBUTES DESCRIBED
1. INCIDENT DESCRIPTION	27
2. GEOGRAPHIC AREA AFFECTED	12
3. GOVERNMENT JURISDICTIONS AFFECTED	6
4. DEMOGRAPHICS OF AFFECTED POPULATION	40
5. HOUSING/BUILDING STOCK AFFECTED	12
6. DEATHS AND INJURIES	2
7. DAMAGED STRUCTURES	11
8. INFRASTRUCTURE DAMAGE	30
9. ANALYSIS OF SECONDARY HAZARDS	14
10 FEDERAL AND STATE ACTIONS	10
11 LOCAL GOVERNMENT/CHAPTER INITIAL ACTIONS	25
12. LOCAL VOLUNTEER ORGANIZATION ACTIONS	8
13. MEDIA CONTACTS AND ACTIVITIES	2
14. SERVICE DELIVERY AND SUPPORT ANALYSIS	51
15. PRE-DISASTER RESPONSE PLANS	7

FIGURE 1

DATA STRUCTURE DIAGRAM OF RED CROSS INFORMATION NEEDS



MEMIS: MULTIMEDIA EMERGENCY MANAGEMENT INFORMATION SYSTEM

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ABSTRACT

As a result of the rapid growth of information and communications technologies, it is expected that more than eighty percent of the management information systems (MISs) in use by the year 2000 will be developed to support the managers themselves [Steger and Bannister, 1992]. These MISs will be built within commercial software development environments, such as spreadsheet and database programs, geographic information systems, expert system shells, visual interactive simulation packages, and hyper- and multimedia authoring tools. The MISs will range from simple spreadsheet programs to complex multimedia spatial decision support systems.

There is no doubt that this development will also affect the emergency management community. In this paper we present a prototype MIS designed for emergency managers: MEMIS (multimedia emergency management information system). The purpose is to show the technological possibilities and ease of development, and the tasks that can be supported by such systems. MEMIS is based on the latest technology for the development of MISs: multimedia, animation, voice and video communication, LAN and WAN, and machine intelligence. MEMIS covers the three most important tasks of an emergency manager: (i) emergency planning (facility management, site selection for hazardous activities, designation of hazardous material shipment routes), (ii) emergency response (notification, monitoring, and response management), and (iii) the daily management work (communications by phone, fax, and e-mail; database and spreadsheet management). MEMIS communicates with (and can control) standard software packages and databases used in the emergency management community, such as CAMEO. Its open architecture makes it easy to incorporate features designed to meet the unique needs of a specified region or nation.

1. INTRODUCTION

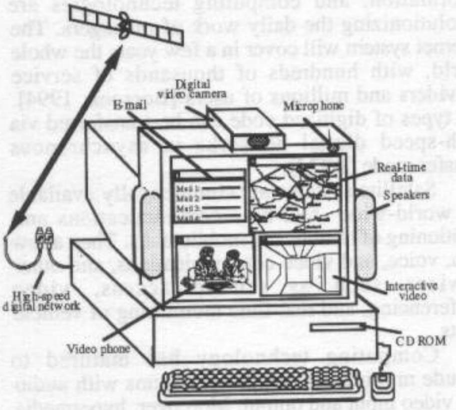
Technological advances in communications, information, and computing technologies are revolutionizing the daily work of managers. The Internet system will cover in a few years the whole world, with hundreds of thousands of service providers and millions of users [Borsook, 1994]. All types of digitized code can be transferred via high-speed digital networks in asynchronous transfer mode (ATM).

Satellite systems are commercially available for world-wide real-time communications and positioning of remote and mobile units. They allow data, voice, and video communications, and other services such as remote access, video conferencing, and real-time monitoring of vehicle fleets.

Computing technology has matured to include multimedia computer systems with audio and video input and output. Moreover, hypermedia and virtual reality are being considered to support decision making in emergency management [Beroggi et al., forthcoming 1995].

The combination of advanced communications, information, and computing technologies results in a desk-top multimedia computing system as illustrated in Figure 1. In a multi-finder system , such as provided by X-Windows under UNIX or the Macintosh computers, multiple applications can run simultaneously. Text e-mail runs next to real-time data acquisition (e.g., for a real-time vehicle tracking system), and video phone (e.g. for a video conference and monitoring) runs next to interactive video (e.g. for a virtual reality application).

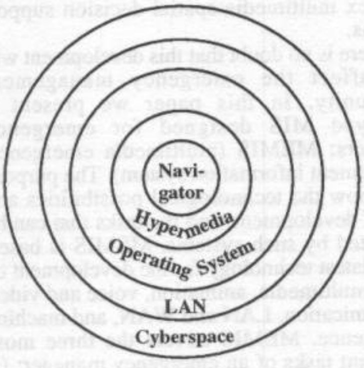
Systems for emergency management using some of these novel technologies have already been developed. An example is CAMEO, a PC-based multimedia emergency management software system for chemical production sites and transportation of hazardous materials [CAMEO, 1993]. Due to its of its user-friendliness it is implemented all over the world. Another example is InterClair, also a PC-based decision-support system, developed by the United Nations Interagency Program [InterClair, 1992]. It assists the practice of environmental modelling for risk assessment and management at basically all three management levels. It has been developed using the latest concepts, such as virtual instruments, animation, hypertext, and knowledge-based systems.



2. THE MEMIS ARCHITECTURE

MEMIS is built in a hypermedia environment in HyperCard on a Macintosh computer. The hypermedia environment is based on the concept of object oriented programming. Objects at lower levels inherit the characteristics of objects at higher levels. An object has the characteristics (attributes; e.g., the size of a card or the shape of a button), and it can perform activities. These activities can be as simple as activating an audio or video message, or as complex as performing an algorithmic procedure that has been coded, e.g., in Pascal.

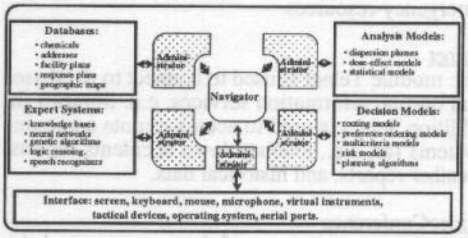
MEMIS is built on a shell principle (see figure below). At the heart of the system is the navigator which controls the system's activities and communicates between the user (emergency manager) and the other levels. The first level, after the navigator, is the hypermedia environment. It has a prestructured architecture which supports the navigator. Codes written in the hypermedia scripting language can be compiled in memory. The code is attached to an object and it can easily be altered. This is especially useful during the development phase. Moreover, the designer of the system can define different user-levels which allow more in-depth access to the code. Thus, experienced users could have access to a lower user-level, while novice users would just have access to the higher levels. Moreover, code can be complied, or written in Pascal or C and attached as external commands. Finally, stand-alone applications can also be generated which make the system independent from the development environment.



The third level is the operating system. Activities at this level are fired with an event handler, similar to the message handler in the hypermedia environment. This handler can start other application, e.g. a word processor, and also control them to a certain extend. In other words, the navigator can also communicate to other frequently used applications (given that they are scriptable), such as word processors, spreadsheet programs, databases, drawing programs, etc.

The fourth level, the local area network (LAN), is basically identical to the previous level. However, it is required that the other work stations allow the navigator of MEMIS to access their file system and their applications. The major advantage of operating MEMIS on a LAN system is that applications and files can be shared among different users.

The last level is cyberspace, the world-wide information and communications network (Internet), based on phone lines, fiber optics, and satellite communications system. MEMIS attached to the Internet allows e-mail, video conferencing, real-time monitoring, remote database access, remote application access, etc.



At the functional level, MEMIS consists of databases, models, application programs, and expert system technology. The core of the system is the navigator that communicates between the human user, i.e., the emergency manager, and the system's main modules. The communications interface between the navigator and the human user is based on different devices, including the computer screen, the keyboard, the computer mouse, microphones, virtual instruments, such as slide bars and radio buttons, and, in the near future, tactical devices, such as gloves. Communications between the navigator and the modules is supported by special administrators. An administrator activates the appropriate model or database, depending on what fits the task best. The four main components of MEMIS are databases, analysis models, decision models, and expert systems components. The figure above shows the functional concept of MEMIS.

3. THE MEMIS MODULES

MEMIS consists of 25 different modules that are accessed or operate at different levels in the shell structure. While some modules are completely integrated into the hypermedia system, other modules reach all the way into cyberspace. Some of the modules are based on the ones used in the CAMEO system. The modules are shown in the navigator (see figure below); a short description of the modules follows.

Memo

The Memo modules is a note pad modules where the emergency manager can place and retrieve notes. Coupled with the E-mail modules, ticklers can be sent to other users.

Agenda

The Agenda module is a calendar which notifies the user automatically appointments, meetings, etc. The notification time can be set, e.g., minutes, hours, or days before the meeting takes place. Together with the E-mail modules, agendas of remote users can be checked. Dates can be entered with notification and confirmation of the other user.

Addresses

The Addresses module contains the database of persons, institutions, emergency response teams, persons to be notified in cases of emergencies, etc. Together with the Phone, E-mail, and WWW modules, phone, fax, and e-mail lines and personal home pages can be accessed by double-clicking on the appropriate numbers. Together with the GIS module, the location of the addresses on the geographic map can be shown.

Phone

The Phone module manages phone and fax messages. Together with the modem on a portable phone, MEMIS can be used as portable system.

Help

The Help module assists the user in the use of MEMIS or in cases of system errors. It can include video and audio instructions, as well as text.

E-mail
The E-mail module is used to communicate to other users and to receive messages from list servers. Examples of list servers in emergency management are: CMTS-L (chemical management and tracking; listserv@cornell.edu), DISPATCH (police, fire, and EMS telecommunications majordomo@comeng.com), EMERG-L (emergency services; listserv@vm.marist.edu), FIRENET (listserv@life.anu.edu.au), HELPNET (network emergency response planning; listserv@vm1. nodak.edu), LEPC (hazardous materials emergency response; listproc@moose.uvm.edu), SAFETY (safety issues; listserv@uvmvm.uvm.edu). Moreover, governmental agencies run also list servers; such as the different EPA lists (e.g., EPA-Waste with all hazardous and solid waste documents; listserv@unixmail.rtpnc.epa.gov).

Usenet
UseNet News is a service that manages articles prepared by people at educational, commercial, and government institutions all around the world. The articles are grouped into news-groups that focus on specific issues. The articles can be read with an appropriate software by contacting a news server. Some of these NewsGroups relevant to emergency management are: alt.disasters.planning, alt.med.ems, misc.emerg-services, sci.med.ems, and uiuc.safety (environmental health and safety forum). In the future, these articles will include graphics (displaying data), photo-graphs, and video, showing simulated situations and real disasters.

WWW
World-wide-web (WWW) is a hypertext client-server-based cross-referencing tool initiated by CERN. It includes file transfer protocol (FTP) and gopher. Further information about WWW can be accessed through anonymous telnet or ftp at info.cern.ch. An interesting WWW site for emergency management is, e.g., Global EMS Archives (http://herbst7.his.ucsf.edu). More information about related WWW, gopher, and ftp sites for emergency management can be obtained through "ftp://hairball.ecst.edu/pub/ems/internet.emergency-resources.

Telnet
The module Telnet is used to connect to databases and on-line information services, e.g. libraries. In addition, telnet is used to access remote computer systems for, e.g., loading down accidents reports, weather reports, and historical data.

VideoConference
With the camera on top of the computer and the appropriate software (e.g., CU-SeeMe from Cornell University), video conferences and monitoring can be performed.

TextEdit
The module TextEdit connects to a common word processor.

TableEdit
The module TableEdit connects to a common spreadsheet program.

Calculator
The module Calculator connects to a calculator system.

GIS
The module GIS connects to a geographic information systems. This can be a commercial

system or a task specific system such as used in CAMEO. The internal system has also zooming capabilities but not all the functionalities of a commercial GIS. This module can be connected to other modules, e.g., Phone, Addresses, Alarm, Emergency, etc. In addition, this module will include global positioning systems for the control of mobile units.

Alarm
The module Alarm dispatches warnings to emergency units and to groups affected by an emergency. It can be coupled with an automatic dialing telecommunications system. An example of an automatic dialing systems is the QuickCall telephone notification system used in the U.S. It is capable of simultaneously and automatically dialing around 1,000 numbers in 15 minutes.

ResponsePlan
The module ResponsePlan contains pre-planned response activities and evacuation procedures. It can be accessed in cases of emergencies.

HazMatDatabases
The module HazMatDatabases contains data about the hazardous substances, such as physical state, level of concern, reportable quantity, etc.

DispersionModel
The module DispersionModel accesses dispersion models for the computation of diffusions. The models can be integrated at the hypermedia level or also at the cyberspace level.

Scenarios
The module Scenarios can be used to devise response strategies. Dispersion plumes in stationary or dynamic systems can be computed.

Weather
The module Weather provides data on storms, local and regional weather conditions, etc., The reports can be accessed by Gopher.

AccidentReports
The module AccidentReports is used to record and compile data on accidents for storage and reporting purposes.

AccidentStatistics
The module AccidentStatistics is a database with historical accidents, which can be purchased by professional accident statistics databases.

InstallationPlans
The module InstallationPlans contains the plans of installations. These includes floor plans, lay-outs of technological systems, and emergency escape routes. The plans are interconnected in a hypermedia system.

Inventory
The module Inventory is a database that supports the management of the facility. It tells what hazardous material is present and where it is stored.

Emergency
The module Emergency is used to manage the response to emergencies. It connects to different other modules, such as Inventory, ResponsePlans, Addresses, Alarm, etc.

TASKS TO BE ADDRESSED IN MEMIS

The MEMIS system can be used for three tasks: daily work tasks, emergency planning, and emergency response.

Daily Tasks
MEMIS is a desk-top system that can be built around a workstation that is used in day-to-day operations in emergency management. Therefore, it integrates the administrative tasks of an emergency manager with the emergency-specific tasks. Text processing, spreadsheet work, database management, and e-mail communications are performed in the same system as emergency management and planning. The advantage is that the user does not need to switch between two different system but all the work is done in one integrated system - MEMIS. With the access to cyberspace, the emergency manager can be kept up to date about new developments. The workstation can be replicated in a labtop configuration for

portability.

Emergency Planning
Scenario analysis, development of response plans, analysis of statistics, etc., are routine tasks. The system can also be used for training and simulating actual incidents event.

Emergency Response
This module includes capabilities such as automatic dialing, alarm, and real-time monitoring. GPS capabilities provides for real-time control of response resources. Routing models and expert systems provide recommendations to the emergency responders. CAMEO and similar models provide predictions of various impacts of the event.

5. CONCLUSIONS

MEMIS was developed in a prototype version to demonstrate how commercially available software and hardware could be integrated to provide emergency managers with an MIS, specifically designed for their needs. It shows that, at a relatively low cost, since most of the capabilities are already installed on personal computers, an emergency manager can have his or her system, and not be dependent upon local, regional, federal, etc. workstations and information systems. In addition, the system can either be installed on or duplicated in a labtop computer for portability and personal use.

The development of a MEMIS can be done by the emergency manager, in concert (if needed) with a person knowledgeable about PCs, word processing, and spread sheets. The addition of modeling capabilities, such as CAMEO, would require knowledge of dispersion models and traffic routing - topics familiar to emergency managers. It is certainly conceivable that every emergency manager could have his or her own MEMIS.

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Rivers and Groundwater Vulnerability to Accidental Pollutions
Spatial Analysis of Vulnerability Areas

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ABSTRACT

The determination of the water resource vulnerability is a necessary step for the prevention of accidental pollution. When rivers or aquifers are used for water supply, it is very useful to forecast pollutant flow velocity in order to determine travel time between the potential pollution points and the intake.

Usually, water resource vulnerability cartography takes only distance from intakes into account. But others physical factors are involved in pollutant propagation : slope and soil texture.

It is necessary to define a method for automatical cartography of vulnerability zones around the intakes. For this aim, we map spatial distribution of the travel time on the resource catchment (river, lake, or well). This typical problem of propagation requires a specifical spatial analysis : start from the river or the well and extend the zone upstream according to the velocity values. It is an iterative process : for each selected cell, the neighbouring cells which contribute to the inflow are first determined. Then, for these cells, the flow velocity values are used to determine a cumulate travel time to the river or to the well. Eventually, we obtain a travel time map which control a good of the vulnerability.

With the aim of decision support for designing protective zones around the rivers and the wells, this method is integrated in a GIS.

The method is tested on two area in the Massif Central (France).

IMPORTANCE OF WATER RESOURCES FOR DRINKING WATER SUPPLIES

To respect drinking water specifications, natural waters are treated. Water treatment has a cost which depends on natural water quality. Local organizations must :

- reduce the accidental pollution risks which treatment cannot purify,
- keep the water quality at the same level or improve it in order not to increase treatment costs.

If it is possible (presence of alluvial aquifers), groundwater resources must be preferred to surface water resources because they are naturally better protected against pollutions. Expoitable groundwater resource (considering criteria such as flow, quality, pumping costs...) is too short in many regions to supply large cities. In this case, surface waters are used. In France, 37 % of the drinking water supplies come from surface resources (LALLEMAND-BARRES and ROUX, 1989).

Water resources vulnerability may be defined as a physical, chemical and biological fragility of a given water environment to a possible pollution.

Characterizing water resources vulnerability constitutes a very important issue which leads us to identify, in time and space, the areas which can endanger natural water quality in case of accidental or chronical pollution. Solving this problem requires :

- knowledge of involved phenomena : pollutant's velocity, pollution flow decrease by infiltration and then adsorption, filtration or biological degradation in soil or in river.
- geographical reasoning because the involved phenomena use parameters which are distributed in space : slope, soil types, etc.

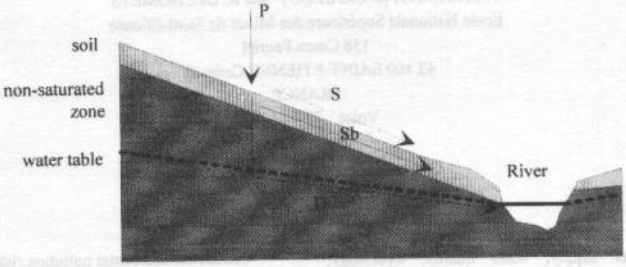
Then, it is necessary to use a method which will integrate these two kinds of knowledge in order to assist to the definition of protective actions. We will restrict ourselves to the physical characterization of vulnerability and we will distinguish the surface waters case from the groundwater case without taking hydraulic interactions between these two kinds of resources into account.

PHYSICAL CHARACTERIZATION OF WATER RESOURCE VULNERABILITY TO AN ACCIDENTAL POLLUTION

Characterization of Surface Water Vulnerability

In order to determine river or lake vulnerability, it is necessary to determine the travel time between any point of catchment and the river or the lake. A river (or a lake) will be all the more vulnerable as a pollution will be able to reach it. If the travel time is long enough, it is possible to intervene in order to stop the pollutant's propagation or to search for an alternate resource.

We can identify three types of runoff in a watershed : a slow flow by permanent groundwater, a quick flow by surface runoff and a quick flow by subsurface runoff in the temporary aquifer (see figure 1).



P : precipitation
S : surface runoff
Sb : subsurface quickflow
D : deep flow in permanent aquifer

figure 1 : flow types on a side

We will not take slow runoff into account because the danger is less urgent.

The surface runoff or saturated overland flow occurs when "on part of the drainage basin, the surface horizon of the soil becomes saturated as a result of either the buildup of a saturated zone above a soil horizon of lower hydraulic conductivity or the rise of a shallow water table to the surface" (PILGRIM and CORDERY, 1992). This phenomenon occurs especially at the bottom of the valley where runoff converges (PILGRIM *et al.*, 1982). So, surface runoff is a rare and space limited phenomenon except when the soil is saturated or impermeable.

The main part of the flow occurs in subsurface. Soil profile usually presents a decrease of hydraulic conductivity with increasing depth because, just beneath the surface, biological activity produces a larger effective porosity than in depth. Often, a temporary groundwater table develops in subsurface and flows out laterally according to a gradient similar to the topographic gradient. It reaches the stream channel quickly and has a large magnitude (PILGRIM and CORDERY, 1992). Then, this process is primordial for rivers or lakes vulnerability characterization, it appears in unfavourable meteorological conditions : wet soils where deep infiltration is limited, and where pollutant adsorption, physical filtration and biological degradation in unsaturated zone are thus difficult.

This characterisation does not take the pollutant's nature into account and assumes that the pollutant is miscible with water. It neglects soil exchange phenomena.

Pollutant travel time depends upon effective velocity u_p which is equivalent to particles velocity in the subsurface saturated zone.

Filtration velocity u_d (in m.s^{-1}) is given by Darcy's law which is defined for a porous medium :

$$u_d = Ki$$

where K : hydraulic conductivity (in m.s^{-1})
i : water table gradient (dimensionless)

In order to calculate effective velocity (in m.s^{-1}) of any water or pollutant molecule in the porous medium, we can take the effective porosity ω_{eff} (dimensionless) into account. This effective porosity is different from total porosity because it neglects the non-gravitational water which covers the surface of soil particles by capillarity.

$$u_p = \frac{Ki}{\omega_{eff}} \qquad (1)$$

We use this law to evaluate groundwater velocity. But in actuality, hydraulic conductivity determination is difficult because a homogeneous medium is an idealized case, which is rare in the field. For this, the real effective velocity has always some uncertainty.

Parameters determination :

- temporary aquifer hydraulic conductivity K is that of the subsurface i.e. that of the first meter of soil,
- water table gradient i : we assimilate it to the topographic gradient,
- effective porosity ω_{eff} : related to the soil texture.

Without field measurments, hydraulic conductivity can be determined by the relationship between this parameter and the soil's texture (RAWLS and BRAKENSIEK, 1983) (see table 1). But, the values given by these authors match those of aquifers. Indeed, with a same texture, the first soil layer (about fifty centimeters beneath the surface) shows higher values on account of vegetal and animal activity or of agricultural modifications (ploughing...). In order to obtain more accurate values, it would be necessary to realize field mesurements, which is impossible in this methodological study. But, BRAKENSIEK *et al.* (1988) reported that ploughing increases soil porosity from 10 to 20 percent depending on soil texture. SKAGGS and KHALEEL (1982) have shown that the infiltration rates are twice as important on a soil under grass as on a bare and crusted soil. From these results, we assume that hydraulic conductivity is twice as important for the soil subsurface as for the bed rock in depth, with a similar texture of course (see Table 1).

Texture	saturated hydraulic conductivity of bed rock K ($m.s^{-1}$)	saturated hydraulic conductivity of soil K ($m.s^{-1}$)
sand	$654 \cdot 10^{-6}$	$1308 \cdot 10^{-6}$
loamy sand	$166 \cdot 10^{-6}$	$332 \cdot 10^{-6}$
sandy loamy	$60.5 \cdot 10^{-6}$	$121 \cdot 10^{-6}$
loam	$36.6 \cdot 10^{-6}$	$73 \cdot 10^{-6}$
silt loam	$18.8 \cdot 10^{-6}$	$38 \cdot 10^{-6}$
sandy clay loam	$8.33 \cdot 10^{-6}$	$17 \cdot 10^{-6}$
clay loam	$5.55 \cdot 10^{-6}$	$11 \cdot 10^{-6}$
silty clay loam	$5.55 \cdot 10^{-6}$	$11 \cdot 10^{-6}$
sandy clay	$3.33 \cdot 10^{-6}$	$7 \cdot 10^{-6}$
silty clay	$2.77 \cdot 10^{-6}$	$6 \cdot 10^{-6}$
clay	$1.66 \cdot 10^{-6}$	$3 \cdot 10^{-6}$

Table 1 : saturated hydraulic conductivity according to texture

In others respects, without measurements of effective porosity, we can use an empirical function defined by ECKIS (cited in DE MARSILY, 1981) which relates effective porosity to soil particles average diameter, i.e. to the texture (Table 2).

particle size (mm)	texture	effective porosity
0.0001	fine clay	0.12
0.001	clay	0.27
0.01	silt	0.33
0.1	fine sand	0.28
1	coarse sand	0.20
10	fine gravel	0.15

Table 2 : effective porosity according to texture

Groundwater Vulnerability Characterization

Involved Factors

Groundwater vulnerability is controlled by the following factors :

- aquifer filtration capacity : weak in porous medium and insignificant in fissurated or karstic rocks ;
- unsaturated zone thickness above aquifer : important natural epuration by adsorption on clay, by mechanical filtration between soil particles or by biological degradation; the main part of adsorption and of biodegradation occurs in the unsaturated zone ;
- groudwater flow velocity : it determines dilution process, pollutant fixation and degradation and pollutant particles effective travel time between pollution point and intake ; ability to give the alert and to intervene depends on this velocity ;
- the type of aquifer : free aquifer or confined aquifer.

Factors Determination

In this study, we are only interested in free aquifers (such as alluvial aquifers) because they are at the same time the most exploited and the most vulnerable.

For the moment, we don't take the self-epuration in the non-saturated zone into account because this phenomena depends largely on pollutant nature and infiltration modelling in non-saturated zones needs different equations and parameters. We assume that the vulnerabilty is only a function of travel time. The pollution danger declines as travel time increases (BARROCU and BIALLO, 1993).

We can use equation (1) in order to determine the particles' effective velocity within the aquifer.

Determination of the equation parameters :

- in the case of a permanent aquifer, the piezometric gradient (given by the water table) does not necessarily match the topographic surface as is the case with a subsurface aquifer,
- the hydraulic conductivity K is that of the aquifer.

VULNERABILITY ZONES AND PROTECTIVE ZONES : « CLASSICAL » DELIMITATION METHODS AND RECENT DEVELOPMENTS

Regulations in force in European countries prescribe the definition of two or three protective zones around groundwater or surface water intake for drinking water supplies. In these areas, certain activities are prohibited or controlled in order to reduce the risks of accidental or chronic pollutions.

In France, hydrogeologists are responsible for the definition of these perimeters. They rely on travel times in accordance with the numerous parameters which we have mentioned before. In alluvial areas, hydrodynamic models exist which can be used to set up these protective zones on a physical basis. But, often, this delimitation is made without modelling (especially for surface water), the expert relies on his knowledge and his experience. Spatial variability of topographical parameters and of hydrogeological phenomena is taken manually and rather subjectively into account. Spatial distribution knowledge and control of these informations at a kilometric scale - between now and the year 2,000, all intakes will be surrounded by protective zones - seem very complex, only decision support computer tools are able to take this complexity into account (storage, consistency control, analysis, vizualisation...). How to determine manually the effects of slope changes, of the covering clay layer distribution or non-saturated zone thickness variation ?

BARROCU and BIALLO (1993) underlined that aquifer vulnerability maps are essential either in the first planning phase of pollution disasters (danger identification, evaluation and zoning) or in later phases (disaster forecast, monitoring system planning, emergency planning, defence planning...).

Geographical Information Systems (GIS) have been used to map groundwater vulnerability to pollution. GIS are able to store flexible information. They are useful to update in a short time the analysis results which are produced by data changes (new well, changes in pumping flow...).

But, as far as we know, GIS is only used in the multicriteria geographical analysis frame. The authors take numerous parameters into account and they overlap different weighted thematic maps (soil, aquifer depth, hydraulic conductivity...) in order to obtain a spatialy distributed index of the vulnerability (ALLER *et al.*, 1987; PEVERIERI *et al.*, 1991; MUNOZ and LANGEVIN, 1991).

But, GIS contribution is not limited to classic map overlapping. Now, several GIS have further developped spatial analysis algorithms (MILLS, 1994).

BARROCU and BIALLO (1993) have already used the groundwater flow directions "to attribute a vulnerability degree of a polygon (area) downstream of a pollutant".

SUGGESTED SPATIAL ANALYSIS METHOD

Representation of Spatial Distribution of Vulnerability Parameters

GIS manage spatial distribution and help to analyse the relationships that exist between certain spatial features.

We use a raster format GIS. The raster format is a regular division of space in square cells organized in a cartesian matrix (called layer) of rows and columns. Each theme is represented by a data layer. Each cell has a value. A raster file (like any layer in a GIS) is georeferenced and has a given resolution which corresponds to the cells size.

Compared with a vector structure, a raster format GIS offers the following benefits :

- better modelling of continuous phenomena (BURROUGH, 1986) : vulnerability is a continuous phenomenon ;
- surface spatial analysis is more advanced because pollution spread modelling is easier with the constant size and shape of spatial units, the parameter value of a localisation is controled by the values of this parameter in surrounding localisations (ESRI, 1991) ;
- overlays are easier (BURROUGH, 1986).

Raster geographical databases are bigger than vectors, but we did not suffer from processing time because our database is limited : our surface water catchment has an area of 67 km² and is treated with a cell resolution of 50 meters ; our surveyed aquifer has an area of 15 km² and is treated with a cell resolution of 50 meters.

Parameters Integration in a Geographical Database

Our geographical database is made of several vector and raster layers. The vector layers are transformed into raster layers for the processing.

We use the following layers :

- for surface water :
  - elevation : raster from the Digital Elevation Model of the Institut de Géographie Nationale (IGN), resolution of 50 m
  - hydrography : vector, accuracy of 25 m
  - soil types : vector, accuracy of 50 m
- for groundwater :
  - elevation : raster from the Digital Elevation Model of the IGN, resolution of 50 m
  - piezometric level : vector, accuracy of 25 m
  - hydraulic conductivity : vector, accuracy of 25 m

Developing an Algorithm for the Representation of Travel Times

We use the GIS functions which relate the cell's value to the neighbouring cells values, since the pollutant propagation is a phenomenon which may be calculated using a continuous map to determine spreading pathways (BURROUGH, 1986).

The vulnerability of a river or a well depends on the travel time t (in seconds) between an upstream point of the aquifer and a well or a river :

$$t = d / u_p$$

where d : path distance (in meters)
u_p : effective velocity (in $m.s^{-1}$)

We want to map spatial distribution of this travel time on the resource catchment (river, lake, or well). We know $1/u_p$ values at each point of catchment after calculation of parameters values of hydraulic conductivity K, effective porosity ω_{eff} and hydraulic gradient i (derived from elevation). We cannot take d as a simple distance to the river or to the well because d is a flow path distance on a relief (topographic or water table).

We suggest the following iterative method (see figure 2) :

a) build a raster layer of $1/u_p$ values

b) assign zero to river or well cells for travel time and take these cells like processing cells

c) select neighbouring cells "flowing" into river or well cells

d) calculate travel time t_{ij} (in seconds) between processing cell i and each neighbouring cell j using the following formula (if a neighbouring cell "flows" into 2 processing cells, keep only the shortest time) :

$$t_{ij} = \frac{d_{ij}}{(U_p)_{ij}}$$

with : d_{ij} distance between the cell i and the cell j (in m)
$(u_p)_{ij}$ mean velocity between the cell i and the cell j (in $m.s^{-1}$) like :

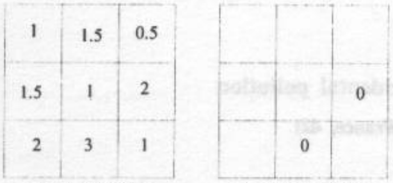
$$(U_p)_{ij} = \frac{(U_p)_i + (U_p)_j}{2}$$

e) consider the previous cells like processing cells and select the neighbouring cells which "flow" into them, give them a cumulate travel time (own travel time + travel time of cells into which they flow)

f) repeat this process for each cell which flows into resource cells directly or indirectly, until the whole catchment is covered.

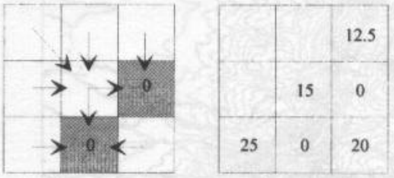
This algorithm is similar to the one which would be used to describe a path cost on a surface with a unit cost distributed in space (this "cost", here, is equal to a travel time : the steeper the slope or the higher the hydraulic conductivity, the shorter the travel time). But, a runoff on a relief is more complex because it is controled by slope direction : we must only consider cells which flow into processing cells and eliminate the others. If we considered only slope amplitude without knowing flow direction, we would give for example a low travel time (or a high vulnerability) to a zone with a high slope, near a water resource but on another catchment.

Then, we use the following criteria in the process : distance between a potential pollution source and the resource, hydraulic conductivity and slope amplitude and direction.



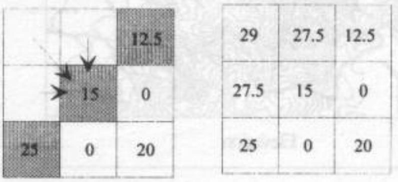
a) (1/Up) values

b) river or well cells



c) cells contributing to the inflow

d) time values for contributing cells



e) cells contributing to the inflow

f) time values for contributing cells

figure 2 : cost-distance spatial analysis

Operators and functions of spatial analysis have been integrated in some GIS, they are based on formal modelling language : map algebra (TOMLIN, 1990). This language is implemented in two popular software packages on the market : ARC/INFO and MGE (Intergraph) (MILLS, 1994). We use ARC/INFO.

The ARC/INFO function being used ("pathdistance") is an algorithm which permits the representation of cells as nodes and links. Each cell center is considered as a node and is connected to the adjacent nodes by links. To each link is affected a "cost" equal to an average "cost" per unit of distance of each cell multiplied by the distance between these cells. If two values of cost-distance are affected to the same cell, then the algorithm keeps the weakest.

The unit's cost is equal to the spatial parameter ($1/u_p$), i.e. it is equal to : $\omega_j / (K_j * i_j)$ (see equation (1)).

This function also permits to consider the flow direction by a vertical factor VF (see equation (2)). In order to take flow direction into account, we must measure the slope between the processing cell and each of the neighbouring cells : if the slope is positive then flow into the processing cell is possible, otherwise there is no flow coming from this direction. In the algorithm, when the slope is positive or null, we assign a "1" value to VF and when the slope is negative (which is the case when the process meets a topographic divide) we give VF a high value (100 for example).

In order to correct the effects of relief projection on a plane, the algorithm is able to give the real distance.

So, the cost-distance, corresponding to the inverse of the vulnerability, is achieved using the following formula :

cost-distance = real distance * VF * cost (2)

Application for Surface Water Vulnerability

We apply the method on a catchment in the north-east of the Massif Central (France) : the Renaison catchment. On this catchment, two dam reservoirs are fed by numerous streams and supply drinking water for the city of Roanne, a town of 50,000 inhabitants.

In order to determine surface water vulnerability, in our application, we use all the river and lake cells as processing cells. The travel times for all their catchments can be calculated.

This catchment of 67 km² is very contrasted : the top is near a 1,300 meter elevation and the lowest point is near 350 meter elevation, soil types are quite different (loamy sand soils on granite in the west mountains, clay or alluvial sand in the east plain).

On the map (see figure 3), we can see the analysis results. We have created zones of equal travel time interval. The zones of low travel time, thus of high vulnerability, are larger in the west where the relief is more broken and the soils have a higher hydraulic conductivity whereas, in the east, the high vulnerable strips are very thin around rivers and lakes.

We must underline the fact that some parameters values have not been measured on the field, they are theoretical values obtained using general tables (see above).

In other respects, cells' spatial resolution of the Digital Elevation Model (elevation map) have produced some errors in the mapping. Low vulnerability isolated cells rise in the middle of high vulnerability cells sometimes near the streams because slopes calculated from data of the DEM are lower, so the cell's velocity is lower and its vulnerability is almost null. Another processing would be necessary in order to clean the data.

Last but not least, we must make it clear that these results are based on assumptions of a porous medium (see above).

Application for Groundwater Vulnerability

Aquifers are exploited by wells. Therefore, this method will be applied for the determination of intakes' vulnerability regarding a potential aquifer pollution.

The vulnerability of an intake depends on the travel time in the aquifer without considering the unsaturated zone.

Such a spatial analysis is similar to the case of surface waters but the hydraulic gradient corresponds to the slope of the water table. We consider the aquifer's permeability.

On figure 4, we can see the travel times on a well's groundwater catchment expressed in days. The well is in an alluvial aquifer near the Loire river in the north east of the Massif Central (France). 25 m^3 per hour are pumped from this well, it causes a deformation of water table which contour lines

Figure 3

River vulnerability to accidental pollution

Renaison catchment (France, 42)

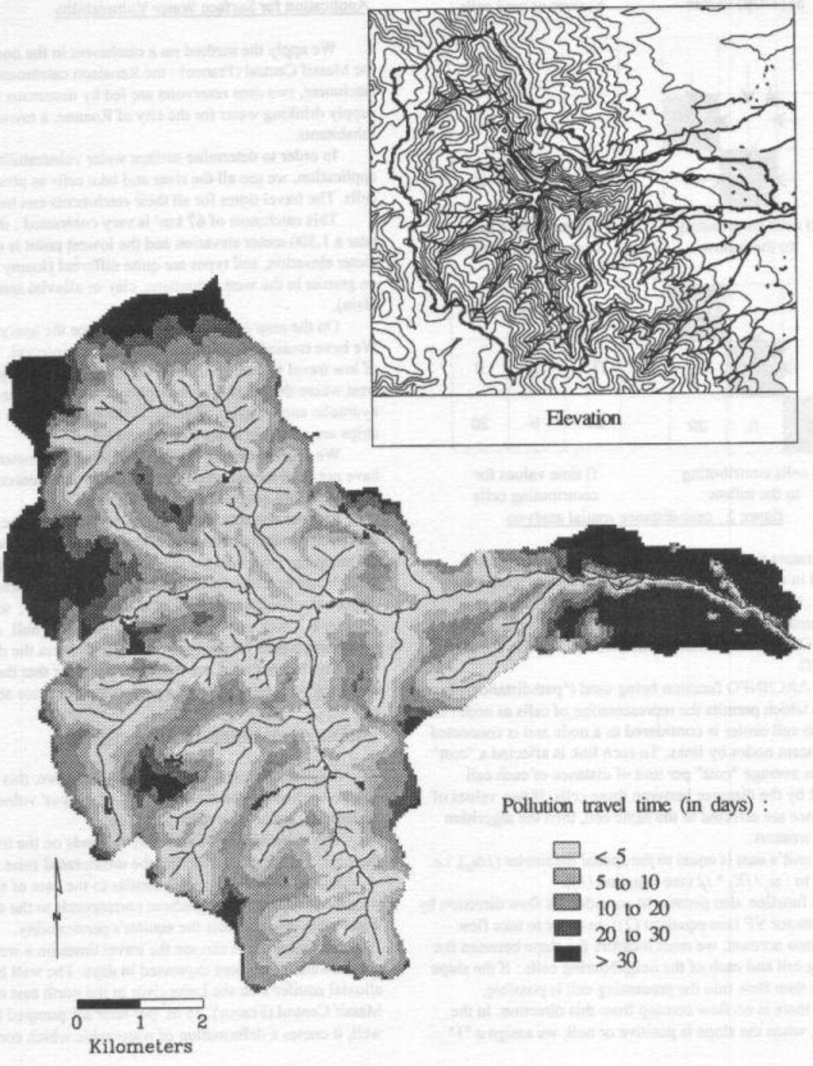
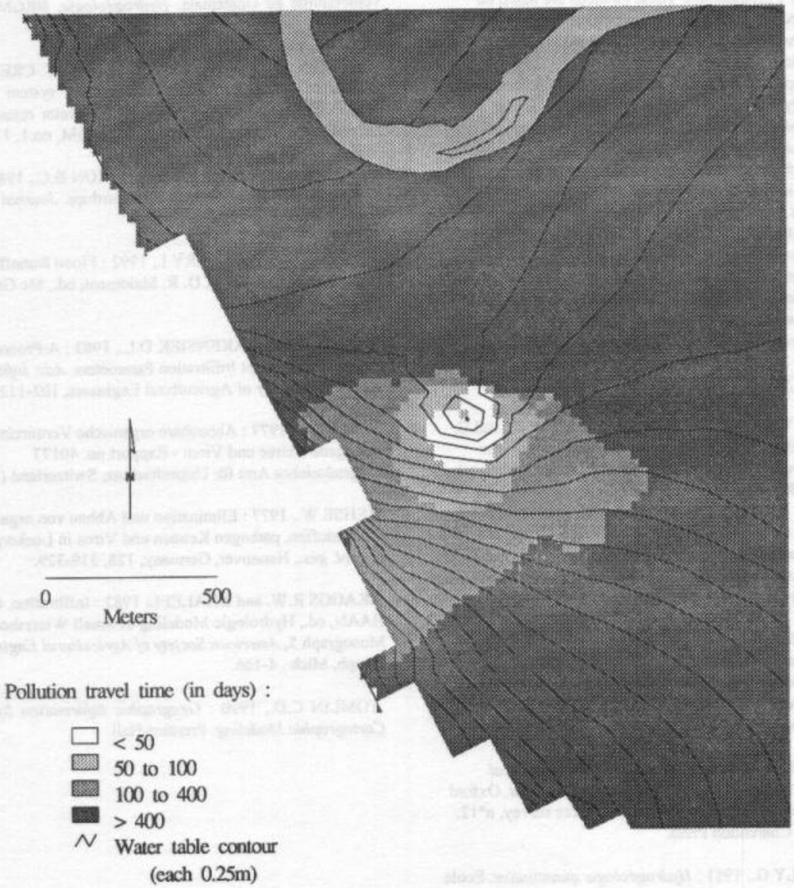


Figure 4

Well vulnerability to pollution

Balbigny aquifer (France, 42)



are represented on the map. The results show some isolated high travel time cells surrounded by cells with a low travel time. They are produced by the same causes as in the case of surface water : insufficient slope knowledge which produces flat cells. This type of error is even more frequent when the hydraulic gradient is weak. Thus, we must underline the fact that the analysis is limited by data resolution.

SPATIAL ANALYSIS AND NUMERICAL MODELLING

The type of transfer considered in our approach is purely convective. Under no circumstances, this spatial analysis should be a substitute for traditional numerical modelling methods of the pollution's propagation. These methods are based on differential equations which are built on the equation of continuity and Darcy's law and which take dispersion and diffusion (Fick's law) into account.

Our approach consists rather in a complementary means in order to analyze and visualize the spatial variability of hydrologic parameters involved in the determination of protective zones.

For such a determination hydrodispersive or hydrodynamical models are not always ready to operate (lack of data, unfitted parameters, calculation time...). But when they are available, pollutants' propagation models are more efficient for a better understanding of hydrodynamical behaviour in order to foresee the impacts of a pollution.

As a conclusion, spatial analysis of hydrological parameters provides a complementary means of numerical and stochastic modelling for groundwater transfer processes.

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PRESENTATION OF GEOGRAPHICAL DATA IN ENVIRONMENTAL INFORMATION SYSTEMS

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KEYWORDS: geographic information system (GIS), environmental information system, categorical thesaurus

ABSTRACT

A model is presented to describe geographic objects in an environmental information system. The model is based on the concept of a categorical thesaurus implemented in a computer reference system.

RAISING THE PROBLEM

Information on environmental disasters currently is presented using a geographic information system (GIS). The so-called "maps of loading" approach came into general use in information systems on pollution, where pollution characteristics are given in different geographical contexts (geophysical, administrative, economical, etc.).

Most GISs are characterized by two types of data: cartographic (or spatial) and attributive. Geographical aspects of a phenomenon, including spatial relations, are presented in a spatial database. An attributive database contains quantitative and qualitative descriptors of geographical objects and their relationships. An attributive database generally does not provide geographical relations; yet, it is an attributive database that is most suitable for presentation of a conceptual model of the subject area, comprising all kinds of relations between objects, including geographical relations.

The presentation of geographical relations of objects becomes urgent for a large attributive database where these relations could comprise conditions for provisional selection of objects. The results of selection can be reflected even through a spatial database.

In this paper, a model is described that presents geographic data in an attributive database related to an environmental information system.

REALIZATION OF THE MODEL

The geographical aspect is one of the basic aspects of information-related environmental activity, since environmental data are usually related to space and time. The subject of the description includes geographical objects (GO) as components of some geoterritorial system (GTS) consisting of GO of different character. The basic type of relation for these systems is a place relation. The GTS is formed from numerous GO (which are homogeneous in a certain sense), if the place relation between them produces a qualitatively new object. For example, an unrelated set of rivers does not generally form a GTS. However, a GTS is formed if a set of rivers connect with each other by a place relation, so that they form a network of rivers flowing into each other and, finally, into a common river, forming a basin of the common river. The place relation here is interpreted as the flow of one river into another. Another example of a GTS, of a different type, is an administrative and political system of the type, "country," with provinces, regions or states being its components. If a set of GO (even homogeneous) does not form an integral unit (e.g., a set of bays of a sea does not comprise a GTS), then itmakes up a geoterritorial complex (GTC). Thus, to comprise a GTS, a set of GO must have a common system-forming property.

The possibilities for an end user in the information system (IS) are determined by the system's thesaurus, i.e., a concept-terminology database. To create a conceptual database (a classifier or thesaurus) for the problem medium (PM), "Geographical Objects and Systems," an approach is proposed based on the idea of a categorical thesaurus. The essence of the approach is that the conceptual model of the specific PM is based on common scientific categories which have their own subject interpretations.

To describe a GO, three groups of categorical facets have been identified: 1) taxonomic, 2) system-related and 3) type-related. The first group includes the following facets: Substrata (Land - L, Ocean - O); Morphology - GEM (Areal -A, Line - L, Point - P); Nature - NTR (Artificial - A, Natural -N). This group yields two classes/taxons: "Natural land lines" (e.g., rivers) — SUB=L, GEM=L, NTR=N and "Artificial land points" (e.g., settlements, observational points) — SUB=L, GEM=P, NTR=A. A taxonomic context makes up an intensional part of the conceptual model of the GO. The second group, the system-related group of facets, comprises an extensional part of the GO model. Six basic classes of GTS are implied here (Figure 1): Global, Continental, Administrative and Political, Sectoral, Production and Economical, and Geophysical. As the Figure shows, the classes of GTS are hierarchical in structure. Each of the GTS in these classes is formed by a set of GO related to one taxon. For example, "country" as a subclass of GTS is formed by the following GO of the taxon: SUB=L, GEM=A, NTR=A. The third group is represented by the type-related category that allows a subject typification of GO in terms of geosystems — rivers, lakes, etc. as natural water bodies of land hydrosystems; settlements, observational points, transport centers as artificial objects of different geosystems, etc. Each of the facets is hierarchical in structure, and this reflects the subject knowledge in the given field. The structure of the facet "Geophysical Systems," for example, represents the structure of knowledge of climatic and vegetation areas, hydrosystems of land and sea, mountainous and other geosystems.

The structure of the facet "Administrative and Political Geosystems" gives a description of the present-day administrative and political division of the countries, etc. Each GO belongs to only one taxon/class. Each GTS is formed by a set of the same class. However, any GO may be described in terms of any GTS of basic classes. For example, meteorological station Dixon (as a type of an observational point on land) can be described in the information system in several contexts: 1) global (Northern Hemisphere/former USSR); 2) continental (Asia/Siberia); 3) administrative (Russian Federation/ Taimyr National District); 4) sectoral (Russian Hydrometeorological Service/Far-East Region/Dixon Hydrometeorological Service); 5) production and economical (East-Siberian Economical Region); 6) geophysical (Arctic tundra). From now on, this object will appear in every query in the information system which has any of the above-mentioned points.

The facet and categorical basis is presented in the computer thesaurus as a database whose elements consist of the following structure: 1) semantic index (SI) determining the position of the given element in the system of categories; 2) term-notion appropriate to the SI; 3) encyclopedic entry (including subject references); 4) coordinates block. The first two elements of the thesaurus are shown in Figure 2 as an example of the base/meteorological station fragment; the last two elements are shown in Figure 3 using, as an example, the Baltic Sea description in the database.

Semantic effectiveness of the computer thesaurus, developed on the categorical basis, is shown by the fact that the conceptual models of different geographical objects can be created from the basic set of conceptual blocks. In technical terms, the effectiveness is shown by the fact that the thesaurus presented can at the same time serve as an off-line computer manual and a source of notion and term databases to be used in different environmental information systems. These databases are easy to include in any information system, comprising (through SI) the whole complex of knowledge of geographical objects contained in the thesaurus. To this end, an external text (ASCII) file, whose structure is similar to that in Figure 2, is selected and produced in the computer thesaurus. The computer thesaurus was developed as an application in RIHMI-WDC of the Russian Hydrometeorological Service (Roshidromet) in the FoxPro 2.0 medium on the PC AT.

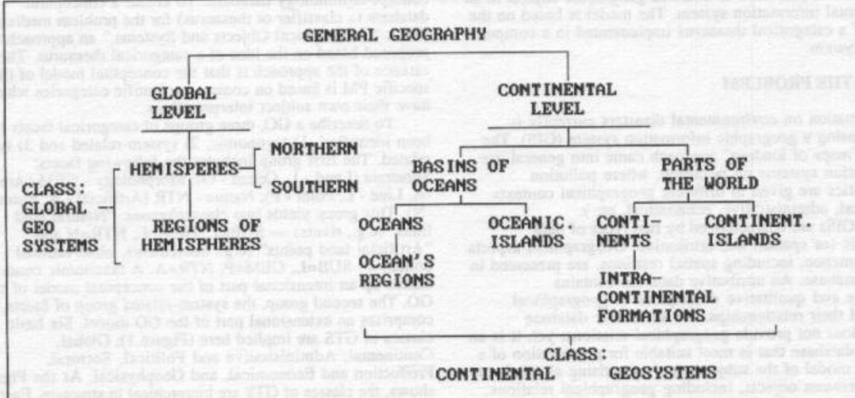


FIGURE 1. HIERARCHIAL STRUCTURES OF TERRITORIAL GEOSYSTEMS

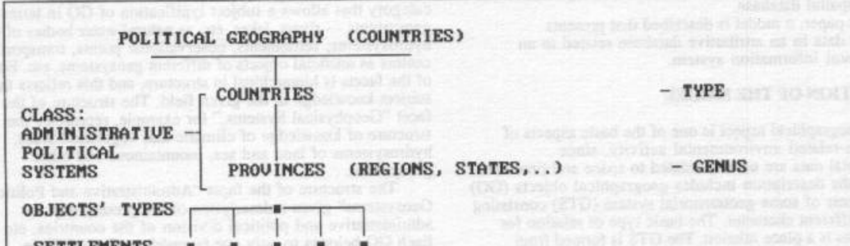


FIGURE 1. (TO BE CONTINUED)

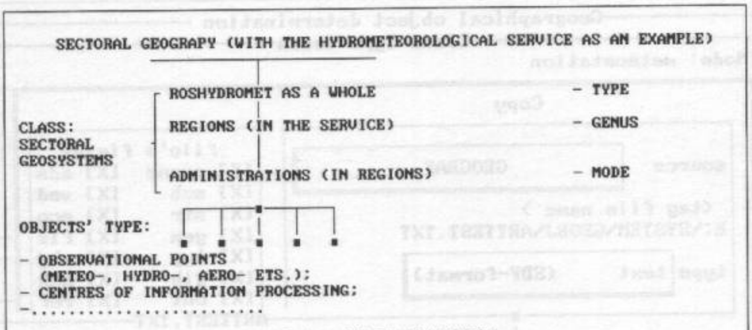


FIGURE 1. (TO BE CONTINUED)

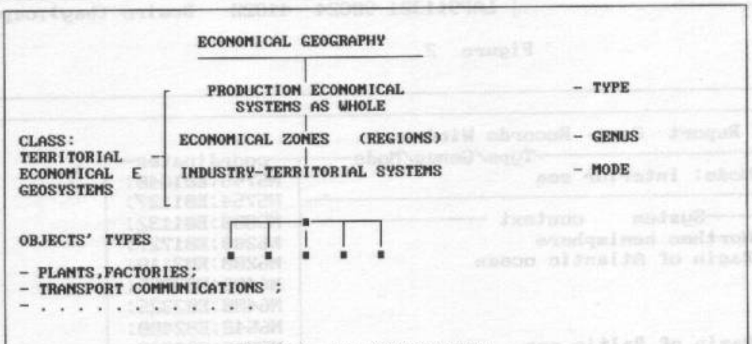


FIGURE 1. (TO BE CONTINUED)

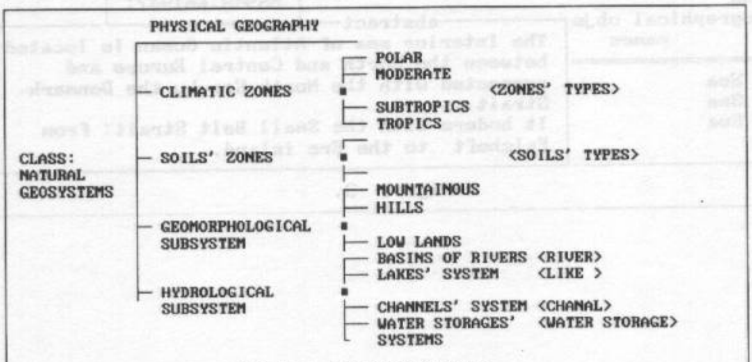
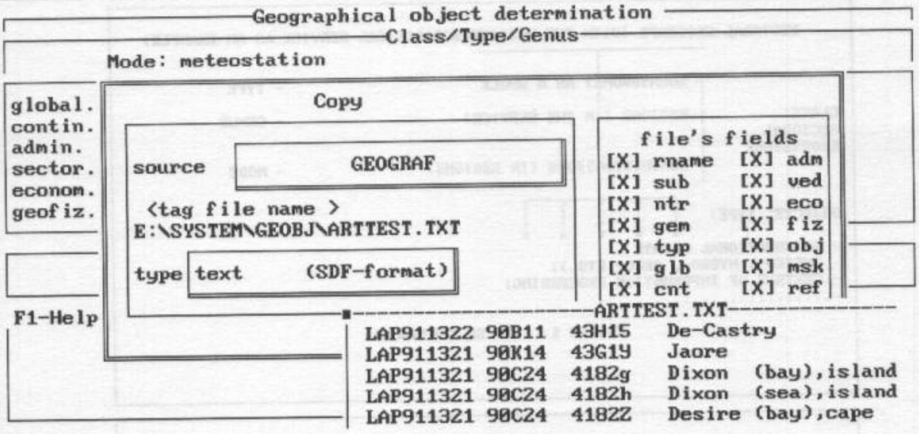


FIGURE 1. (TO BE CONTINUED)



Geographical object determination

Class/Type/Genus

Mode: meteostation

global.
contin.
admin.
sector.
econom.
geofiz.

F1-Help

Copy

source GEOGRAF

<tag file name >
E:\SYSTEM\GEOBJ\ARTTEST.TXT

type text (SDF-format)

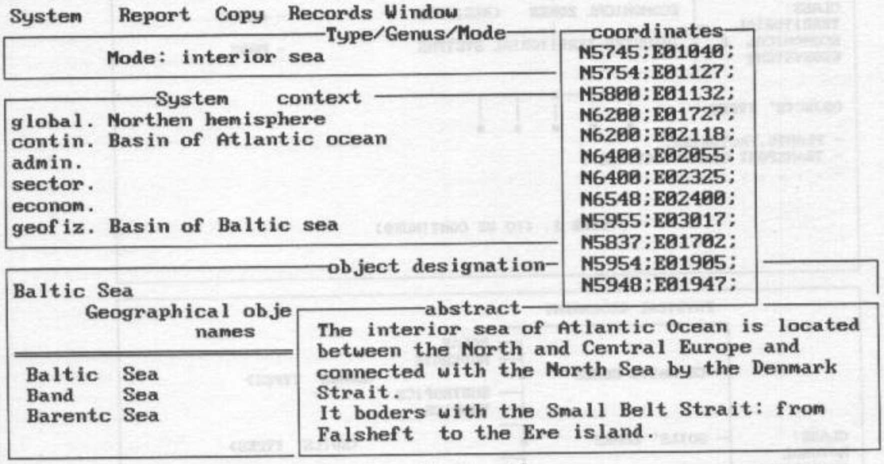
file's fields

[X] rname [X] adm
[X] sub [X] ved
[X] ntr [X] eco
[X] gem [X] fiz
[X] typ [X] obj
[X] glb [X] msk
[X] cnt [X] ref

ARTTEST.TXT

```
LAP911322 90B11  43H15   De-Castry
LAP911321 90K14  43G1Y   Jaore
LAP911321 90C24  4182g   Dixon  (bay),island
LAP911321 90C24  4182h   Dixon  (sea),island
LAP911321 90C24  4182Z   Desire (bay),cape
```

Figure 2.



System Report Copy Records Window

Type/Genus/Mode

Mode: interior sea

System context

global. Northen hemisphere
contin. Basin of Atlantic ocean
admin.
sector.
econom.
geofiz. Basin of Baltic sea

coordinates

```
N5745;E01040;
N5754;E01127;
N5800;E01132;
N6200;E01727;
N6200;E02118;
N6400;E02055;
N6400;E02325;
N6548;E02400;
N5955;E03017;
N5837;E01702;
N5954;E01905;
N5948;E01947;
```

object designation

Baltic Sea

Geographical obje
names

Baltic Sea
Band Sea
Barentc Sea

abstract

The interior sea of Atlantic Ocean is located between the North and Central Europe and connected with the North Sea by the Denmark Strait.
It boders with the Small Belt Strait: from Falsheft to the Ere island.

Figure 3.

PRINCIPLES OF MAPPING SUPPORT IN GEOGRAPHIC INFORMATION SYSTEMS

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KEYWORDS: geographic information systems, mapping.

ABSTRACT

The use of different ways of presenting geographic maps on PCs depends on the GIS objective. In this paper some techniques for preparing map data are described and illustrated.

INTRODUCTION

The main idea of a Geographic Information System (GIS) is visualization of some kind of objects on a geographic map which is drawn on the screen of a computer display. So the first task for every GIS is to draw the map of the chosen geographic area on the screen. There are several principles of drawing geographic maps on a PC screen. Their use depends on the goals of the GIS.

RASTER MAPS

If the user of a GIS needs the map of only one region without any zooming during his work, then one raster image (obtained via scanner) will be enough. In this case we can slightly zoom this map (with 2,4 or 8 magnification) and the picture will be good enough for work. For example, the point on the initial image (on the screen) which was drawn as one pixel after double zooming becomes a small rectangle with size 2x2 pixels. Lines will be twice as thick and so on. So after very deep zooming the picture on the screen will consist of very large rectangles of different colors (every pixel becomes a rectangle) and will be very unpleasant for viewing. This means of map presentation can be used if the degree of zooming is not very big. As an illustration of this way of map presentation we can show the elements of mapping support of the Tsunami Modeling System (TMS) which was developed at Novosibirsk Computing Center for tsunami warning and research purposes (Gusiakov *et al.* 1992). On figure 1 the map of the Pacific is shown. From this raster picture we can choose a sub-region using a moving frame. The map of this sub-region then can be magnified up to almost the whole screen (fig.2). After this it is necessary to pick up a small region for tsunami modeling. The size of the chosen geographic area will be stretched to the size of the drawing field. So, if the area is rather smaller than our sub-region the picture of the chosen area will be unpleasant (Fig.3).

VECTOR MAPS

If the user of a GIS is going to use very deep zooming, the map must be used in vector form. This means that all the elements of the map during visualization on the screen will be drawn as points or pen movements. The advantage of this approach is independence of the point object size (or the thickness of lines) from the zooming degree. In a global GIS, coordinates of map elements are usually stored as absolute geographic coordinates (latitude and longitude); but in regional or local GIS's it is possible to use relative coordinates (relatively to boundaries of the initial region). An example of a very compact global GIS is one for visualizing different kind of point objects (for example, earthquake epicenters) on a PC screen. Mapping support of this kind was developed at Novosibirsk Computing Center. Absolute geographic coordinates of points along the coastlines, rivers, shores of lakes, and state boundaries are stored in the computer memory and can be drawn on the screen after selection of a geographic area. Locations of cities and their names also can be drawn. Map output on the screen is realized in two projections: 1) Rectangular projection (each cell of the geographic grid has the form of rectangle), 2) Orthographic projection (the point of view is located on a line normal to the Earth surface). The initial selection of a geographic region is made from a map of the globe (Fig.4). The rotation of the globe is made by pressing the space button on the keyboard. After the selection, elements of the map can be drawn on the active field of the screen. Menu buttons execute the drawing of corresponding geographic elements (rivers, lakes, boundaries, relief, cities, etc.) and other objects (Fig.5). On the displayed map it is possible to make the next choice of geographic area. Vector presentation of the map permits us to make a very deep zooming of the map. The limit of zooming depends on data format. The GIS which is described here has an 0.2 minute spatial resolution for global data.

UPDATING OF GEOGRAPHIC DATA.

For systems which use vector drawing of geographic maps the problem of vectorization of maps arises. There are some institutions and corporations (ArcInfo, MapInfo, EIS and some others) where you can order digital data for your GIS in a specific format. But if the user needs a very detailed electronic map of some region it is not difficult to input geographic elements into the computer from an original map. Some technologies for updating geographic information are briefly described here. This work can be done in two ways: manually or semi- automatically. First we'll describe the so called "mouse" technology. Here it is necessary to obtain a fit-to-screen graphic image of our region (or its part). This step can be done using a scanner and graphic editor. Then we run the digitizing program and tracing along isolines with the help of a mouse we input screen coordinates of the cursor position into the computer by clicking the mouse button. During this procedure all the points we want to input will be plotted and connected by a specified color on the screen. For linking screen coordinates to the geographic grid it is necessary to input screen coordinates of the upper left and lower right corners of the digitizing area (where the geographic coordinates are known).

Some years ago the author used a table digitizer for inputting coordinates of map elements. Resolution was good enough (0.1 mm) for our goals. The advantage of this kind of equipment is the possibility to work with large sheets of paper (up to 1x1 m). But, disadvantages are difficulties with fixing of the chart during the whole process of digitizing and the impossibility of determining line segments which are already digitized. In some cases the use of large table digitizers is more effective than the "mouse" technology described here.

There is another way to get screen coordinates of line points without using a mouse. This technique is more automated but also needs some handling. In this technology the black-and-white (b/w) raster image of a chosen part of an original bathymetry chart is transformed into a bitmap, using the structure of a graphical format (usually we use the TIFF format). Then a program transfers the raster graphic image into vector form. It means that all elements of the picture will be recorded as pen movements with indicators of pen rising, during its tracing from element to element. The result of this procedure will be a sequence of pairs of integer screen coordinates of points along all lines on the initial picture. Usually the size of a scanned image (with resolution 150 dpi) is up to 1200x1200 pixels. A personal computer is powerful enough to vectorize such a bitmap. As an illustration of the vectorization process let's look at figure 6, where the raster image (after scanning of part of a bathymetry chart) is shown in the upper part and the vector image is in the bottom. In the vector image we have got, it is necessary to remove some map "noise" (titles and other useless lines). A special program easily sorts all line segments, saving some of them as coastlines, as rivers, as boundaries, as isobats etc. Only in this step some handling with the help of a keyboard is needed. A few words about color scanning: If on the original map different geographic elements are drawn with different colors, we can use this circumstance to avoid the procedure of sorting line segments. But here some new problems arise. During color scanning map elements of the same type can be recorded with different colors, so we have to prepare our graphic image for further work with the help of a graphic editor or some other technique. As the result of updated technology one can view the map of Shikotan island (South Kurils)(Fig.7). The geographic data (coastline) in the GIS was improved after the major earthquake and tsunami on 4.10.1994. This was caused by the necessity of pointing out different harbors around this small island.

CONCLUSION

There are different ways of presenting geographic maps on PCs. Use of them depends on the GIS objective. In this paper some techniques for preparing map data are proposed. As examples, a few GIS's for earthquake and tsunami research are shown. They were developed at Novosibirsk Computing Center with different mapping support.

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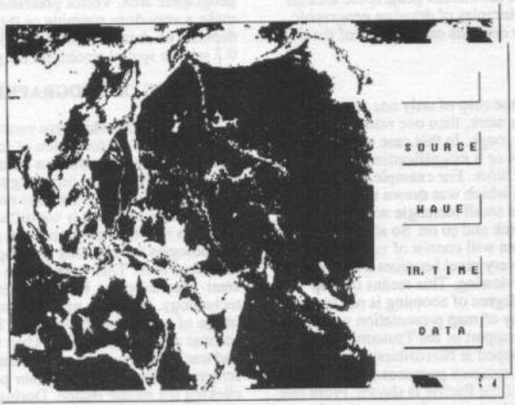

Fig.1 Selection of a geographic region from a raster map of the whole Pacific.

Fig.2 Selection of a small geographic area from a map of the Southwest Pacific. Using a moving frame one can choose an area in the Solomon Sea for tsunami simulation.

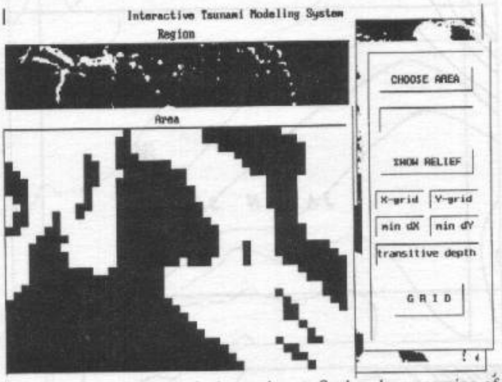

Fig.3 The area in the Solomon Sea selected for the numerical experiment. Such a deep zooming of the geographic map makes the picture unpleasant.

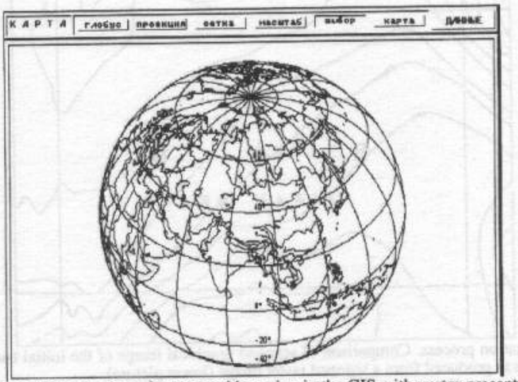

Fig.4 Map of the globe for initial selection of a geographic region in the GIS with vector presentation of map elements.

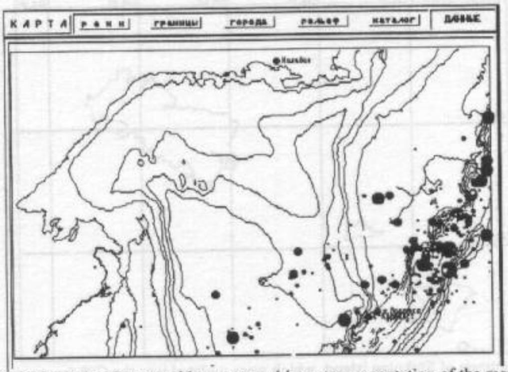

Fig.5 Example of geographic support with vector presentation of the map.

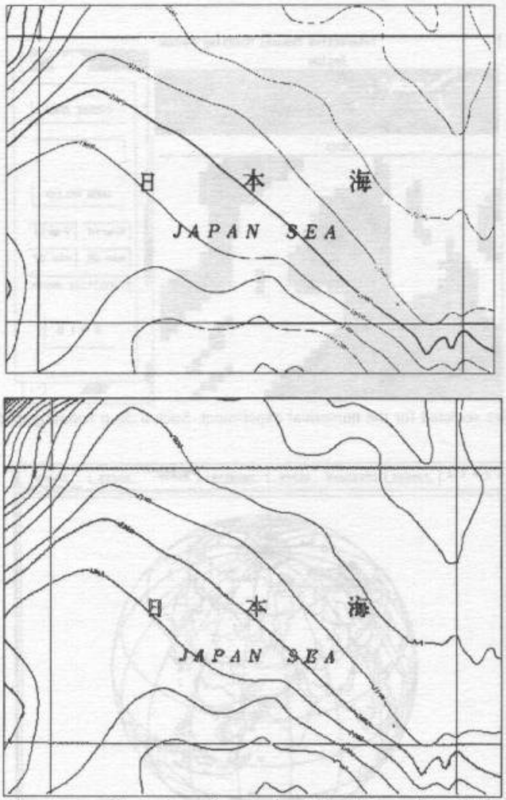

Fig.6 Illustration of the vectorization process. Comparison of scanned graphical image of the initial bathymetry chart (upper picture) with the vectorized one, which was produced from a scanned raster image (lower picture).

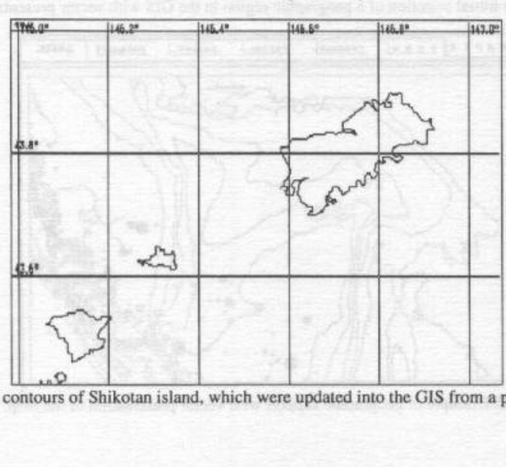

Fig.7 The contours of Shikotan island, which were updated into the GIS from a paper chart.

TIEMEC '95

Decision Support Systems: Research

Chair:
Ross Newkirk
University of Waterloo

Vice Chair:
E. D. Vyazilov
RIHMI-WDC

LOADING THE DECISION SUPPORT SYSTEM WITH KNOWLEDGE FOR EMERGENCY MANAGEMENT UNDER NATURAL DISASTERS

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KEYWORDS

decision support systems, natural disasters

ABSTRACT

A methodology for identifying information to be included in decision support systems (DSS) is offered for use in emergency management. The developed classification of impacts and associated recommendations are applied in the creation of DSS for emergencies.

INTRODUCTION

The most complex and laborious tasks in developing decision support systems (DSS) for various emergency cases are the creation of knowledge bases which characterize the impact of natural disasters (ND) on functioning industry objects, and working out recommendations depending on the full description of situations, type of information, etc. (Vyazilov *et al.* 1991).

Acquiring knowledge is a process of searching various information sources, converting the information to the forms needed, and transference of the information to the data base of the intelligent system. Knowledge sources can include handbooks, books, papers, manuals and instructions, other bases' contents, and other such commonly available information sources. Another type of knowledge is experts' personal knowledge, which is not documented in published sources or stored in depositories.

These sources include personal knowledge, intuition, experience, and problem-solving skill which is passed from teacher to pupil via joint problem-solving and analysis of achievements and failures. Another type of subjective knowledge is empirical knowledge, obtained for the intelligent system via observations and processing of the data base on the environmental state. By identifying the impacts and working out recommendations, it is possible to use historical data from different reports and documents of the services that take preventive measures prior to and manage recovery following disasters.

It is common knowledge that a person cannot inform you about the general abstract rules that he applies in solving some specific task. Most often, a human skill is practiced on a subconscious level. Acquiring knowledge involves a process similar to the creation of a DSS, including different types of activity: stating a problem, acquiring the data, making a choice, and developing a knowledge presentation format (designing, programming, documenting, etc.). This process comprises several stages: analyzing the application of information on the environmental state of the object, identifying the environmental parameters affecting the considered object; choosing the proper information on different kinds of activity in various sectors of the national economy; determining the ND impact on the object; working out recommendations for considering the impacts; creating a logical knowledge base scheme; and, entering knowledge and data bases on computer media.

Let us consider in greater detail the problems related to the determination of ND impacts on industry objects and preparation of recommendations for decreasing or preventing those impacts.

DETERMINATION OF IMPACTS

When assessing ND impacts, in order to make the damage or benefits evident, and determine a range of possible actions, it is necessary to: estimate the extent to which the region has been developed; find out what disasters occur and estimate their probability of occurrence; classify regional environmental challenges with respect to the specific fields of activities; prepare the scheme of applying this information in managing technological processes at the industrial object; and, assess the extent to which the consumer is vulnerable to a change of environmental conditions and dependent upon information quality. After damage is correctly estimated on the basis of joint information, on both the environmental state and economic information, a study should be made of the choice of preventive measures to diminish the damage or increase the benefits. Estimation should also be made of possible effects of the preventive measures and their effectiveness in the course of time. Techniques should be developed for information processing to serve the user, as well as to work out algorithms for decision making, reasoning from some certain information.

Natural disaster impact on an object depends on its intensity (environmental parameter values), characterized as a numerical index. Hence, in assessin environmental impacts on an object, it is necessary to single out the critical values of environmental parameters. Because the need to take measures depends on the probability of prognostic and climatic values of environmental parameters, this characteristic can be included in the knowledge base.

In text these impacts can be expressed using the following verbs: causes, affects, perishes. Depending on the situations for their proper estimation, the verbs are given in different time aspects with respect to information type:

prognostic—may be, possibly;

climatic (background)—hinders, subjects, reaches;
current—loses, shifts, gets;
past weather (with respect to the situation)—broken, damaged.

The character of impacts can be physical, dynamic, heat, chemical, pollution, or social. The results of natural disasters' impacts can be negative and positive.

By evaluating the results of impacts, dangerous areas of an object can be determined as well as the intensity of an impact. Having determined the dangerous areas it is possible to detect the causes of negative effects and eliminate them. It is somewhat difficult to plan and carry out special actions to decrease ND impacts, especially when none of the environmental parameters reaches a critical value. Therefore, integral indicators are to be introduced, such as the climate severity, reasoning from which certain preventive and rescue measures should be taken relative to human resources and property.

WORKING OUT RECOMMENDATIONS

The last stage of processing data on the environmental state is working out recommendations. On the basis of all available information and the character of impacts, a list of recommendations is prepared for making decisions at the objects. The recommendations are presented by non-formalized information on decisions which must be realized under natural disasters. Plans of actions (recommendations) to be undertaken in case of emergency are necessary for making fast reports to the heads of objects. Such plans are prepared beforehand with respect to specific disasters, their consequences, and certain groups of objects or separate technological processes.

In recommendations produced by DSS for emergencies, the functions of groups representing emergency commissions should be given, along with their heads' names, office, and home telephone numbers. In addition, agreements should be reflected with enterprises and governing bodies who are able to render assistance from outside in case of an emergency on the local scale.

After a disaster occurs specific measures are taken to remove the damage caused depending on the character and intensity of the phenomena. Hence, in the data base description there should be a corresponding section, "after a disaster occurs".

There is a great variety of recommendations, since a specific plan of action should be provided for each disaster impact. The types of measures taken may be biological, technical, organizational, economical, or legal. They can also be defined as warning, prohibiting, and ordering, or as measures of prioritizing services.

Depending on the type of information used and the promptness of the decision, tactical or strategic operations can be recommended. Prompt operations are needed for making fast decisions. They are prepared on the basis of short-term prognostic information or on current emergency information and are needed for different purposes, such as: planning a port's work schedule, making up daily projects for fisheries and drilling, taking measures to prevent the damage, or choosing the optimal shipping route through the oceans.

Tactical operations are needed for taking decisions for the nearest period of time (a few weeks or a month), and are prepared on the basis of long-term prognostic information and information on the state of the object. These are necessary for the effective use of the national economy objects, such as choosing efficient methods for the use of fishing tackles, information for the monthly planning of a port's work, providing safe realization of hydraulic projects, etc.

Recommendations for strategic actions involve providing advice to decision makers on decisions to be made in the coming months and years on the basis of extra long-term prognostic or climatic information. These are also needed, for example, for making shipping plans for a season, a year or five-years; for planning hydraulic projects realization; and for choosing the most effective construction of oil derrick depending on the area of its future location.

Recommendations for taking tactical actions are represented by information necessary for decision making for the coming day or weeks, and are partially prepared on the basis of short-term and long-term forecasts. These recommendations are needed for planning work in a port for a week, cargo stowing, fisheries engineering, etc.

At a lower level, objects for which the recommendations are produced are represented by individual enterprises such as middle level municipal governing authorities; at a higher level, by ministries and agencies. Each level is characterized by the range of decisions made over a span of time for which the forecast holds true, the extent of decision accuracy, and a complete description of the resources used. The functions of each level of management are realized through the corresponding algorithm of management, including a number of management procedures—a set of interrelated operations, actions and calculations, carried out within a certain span of time in the process of working out the decisions.

At a lower level, recommendations are made for every enterprise, ship, port, or drilling platform, with specific actions to be taken in each case separately. Prompt actions are recommended for municipal (district) leaders. Recommendations are prepared for the state bodies and also agencies under municipal authorities (civil defense, municipal engineering, communication, militia, sanitary service, etc.). Both prompt and tactical actions are used here.

Recommendations on an industrial scale are needed to perform the control of an enterprise's activity, to provide assistance to them under natural disasters, and to draw up promising projects in developing sectors of the national economy and their output products. Such recommendations are dependent on environmental conditions. Tactical and strategic actions should be used.

Recommendations on a regional scale are prepared for standard objects irrespective of the branch of industry they are related to. These are, for example, ships, water-development projects, populated areas on the sea coast, and a number of enterprises of the same type under one agency (such as fish canneries).

Recommendations to be realized on a large-scale are prepared for planning construction of large-sized installations whose operation can influence the climate of separate regions of the country, such as construction of high and low tide electric power stations, flood protection construction in St. Petersburg, and water intake from Amu-Darya and Syr-Darya feeding the Aral sea. Because the realization of such projects can have unfavorable effects on the natural environment of other countries, the national interests of the countries concerned should be considered in the recommendations.

Specific recommendations can include:

WARNING—if a disaster warning is given, preventive measures should be taken to avoid or decrease the damage and losses.

RESTRICTION—if a restriction warning is given, reasoning from information about poor conditions in a certain region or the ocean area, limitations are imposed on shipping routes and optimal routes are offered to avoid cyclones, floating ice, etc.

PROHIBITION—a prohibition recommendation is given to close a specific region for shipping due to a dangerous disaster; or to withdraw all ships from the region under severe icing, icebergs, poor icing conditions, or hurricanes; or to prohibit a ship's travel into a port or region, when the ship's displacement is less than 1000 tons.

ORDER—ordering recommendations are produced to increase the efficiency of technological processes output, such as identifying promising fishing regions; determining an optimal assurance factor in water development projects; or imposing restrictions on cargo shipping or the speed of vessels.

SPECIFIC INFORMATION—such information may include, for example, data on depth, synoptic conditions in the region, orplaces to take shelter in nasty weather.

Additional information can contain the following: distance to a dangerous area, type of danger, its duration, and limitation on the time of staying in that area.

The choice of protective measures depends on the time of warning, ways of protection, technical facilities availability and their efficiency, and also on other peoples' activities.

Recommendations for decision-making are prepared by experts by drawing on their previous personal experience, on the basis of analysis and generalization of the experience of a group of experts, and also by board advice, considering options both with and without optimization.

If some certain measures are taken at a higher level, they are subsequently realized as specific operations at a regional and local level. Under such circumstances along with the objective of the work, it is of great importance to consider the safety of people and property, as well as the efficiency of plant functioning.

THE POSSIBILITIES OF COMPUTERIZATION OF KNOWLEDGE ACQUISITION

The process of knowledge acquisition is a difficult one. Two directions of studies are possible: 1) computerization of the knowledge base, and 2) automatization of the process for providing completeness and correctness of the recommendation and message bases for various situations. To computerize the data base creation, an editor is applied in the shell SPRINT which makes possible transference of the parameter and function names along with other attributes into the data base. But, computerization cannot solve all problems. The second direction seems to be more important at the present stage of the DSS creation, because many messages and recommendations prepared for one subsystem can be applied to other subsystems. Relying on available messages and recommendations, the experts can perform updating and editing.

It is important to identify the list of standard ways in which natural disasters impact industrial objects. Having the list of standard impacts in the base one can make a prognosis of the impact results.

We offer the theory of solving inventive tasks, particularly the method of "diversion analysis" (Zlotin and Zusman 1991), as a methodology for computerization of the process providing completeness and correctness of data knowledge. On the basis of an accumulated base of messages, classification is made and the standard results of hazardous impacts are identified for natural disasters. Thus, the new or edited messages are entered into the proper DSS bases.

CONCLUSION

A methodology for identifying information to be included in decision support systems (DSS) is offered for use in emergency management. The developed classification of impacts and associated recommendations are applied in the creation of DSS for emergencies.

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IPDS: INTEGRATED PLANNING DECISION SUPPORT SYSTEM

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KEYWORDS: **IPDS, Decision Support Systems, Planning, Hazards, Vulnerability, Risk**

ABSTRACT

The Integrated Planning Decision Support System (IPDS) is designed as a decision support system (DSS) to assist governments and communities in evaluation of geological hazards, vulnerability, and risk. It is at the same way designed to assist an urban planner in organizing, analyzing, modifying, and reevaluating existing or needed spatial information within land-use planning activities improving life stability through risk mitigation. The IPDS system incorporates the Geographic Information Systems (GIS) Geographic Resource Analysis Support System (GRASS) and engineering numerical models within a Graphic User Interface (GUI), to provide the user with comprehensive modelling capabilities for geological hazards, vulnerability, and risk assessment. The methodology that IPDS follows for the evaluation of hazards takes into account the weight of each influencing factor within hazardous geologic processes. IPDS interactive algorithms compute the following parameters for each cell (based on the maximum resolution of the data): the related hazard, the vulnerability to geological hazards, and the risk. One purpose of this DSS is the definition of land-use suitability categories for urban planning. The interdisciplinary formulation of optimum plans for land-use is one of the goals of IPDS, this goal is obtained by providing the user a dynamic user-friendly environment for modeling.

This DSS incorporates the following information: topography, aspect, bedrock and surficial geology, structural geology, geomorphology, soils (geotechnical data), land cover, land-use, hydrology, precipitation (annual average and probable maximum), Federal Emergency Management Agency floodway maps (1986), and historic data to assess hazards. IPDS is designed to assess any "generic" hazard, such as debris flows, subsidence, and floods, with probable maximum precipitation and seismicity as triggering factors for susceptibility scenarios. The regular items considered in vulnerability analysis are (1) ecosystem sensitivity, (2) economic vulnerability, and (3) social infrastructure vulnerability. The risk is assessed as a function of hazard and vulnerability.

INTRODUCTION

Since humans have started to modify nature for development without consideration of environmental processes, the incidence of such dangerous events as landslides, debris flows, rock fall, floods, and wildfires has increased. The magnitude of these hazards and the associated risk intensity posed by such events grows proportionally with population density. Because of the continuing reduction of available stable lands for urban population growth and the high pressure for new subdivisions on unstable lands surrounding urban areas, the need for risk and vulnerability reduction programs, and for restoration, maintenance, and management decisions in settled areas has become a major component of the overall management effort of urban planners around the world.

Natural disasters are considered as very complex phenomena that demand interrelations among geologists, civil engineers, geographers, planners, sociologists, and many others. Because of the complex nature of the interrelations among all the different components of these type of problems, a Decision Support System (DSS) called Integrated Planning Decision Support System (IPDS) is proposed as a framework for the development of an overall plan. This interactive computer system has been developed to create, run, save, and analyze the results of modeled environmental scenarios. The study assesses geological hazards, vulnerability, and risks, to configure a land use suitability zoning model for urban planning based on weighted average of many different factors. To obtain this, the purpose and scope of the study had to include sufficient information to prepare comprehensive maps and descriptive analyses through computer-based modelling concerning the environmental and engineering characteristics of projected urban areas.

Goals A common goal of professionals working with urban development is to achieve specified acceptable levels of stability for humans and social infrastructure in connection with the ecosystem. The size of urban development is determined by the ability of the environment to satisfy the requirements of low hazards, and by the stability of services such as transportation, electricity, water, etc. Therefore, the main goal of IPDS, as an environmental tool is ***to optimize social habitat, thereby improving life stability.*** To reach this, our main objective is the development of a DSS oriented to land use management, with the incorporation of information on geology, geotechnics, geographic information systems, sociology, hydrology, and computer science.

An effective human habitat development plan must prescribe the actions to be taken in terms of social development interest, specific location characteristics (Nevo and García, 1993), and improvement of this scenario. In this project, the objective of such a plan is defined as minimizing the risk to any development. This can be accomplished by improving the knowledge of existing hazard conditions and distribution, and through social zoning, evaluating the existing vulnerability of human settlements, critical facilities and public assembly sites. Finally, as a projected goal in this research, the future objectives of IPDS are to define the optimization of the land use supported with the minimization of the natural risks and the minimization of the cost of landscape modifications that are necessary to satisfy, as closely as possible, the stated Land Use Suitability Index (LUSI) or social needs within its development.

Previous Work Recent advances in computer technology, and in the understanding of how computers can aid organizational decision-making in uncertain environments, have lead to an increasing interest in automated models to handle GIS. Yet relatively limited work has addressed general geological hazard and vulnerability assessment and mitigation planning. Working with a PC-GIS software, Mora and Vahrson (1992) delineated a

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methodology for landslide determination; DeBalogh et al. (1983), and Dong et al. (1988) worked on vulnerability mitigation with emphasis on earthquakes; and Emmi and Horton (1993) developed a model of seismic risk assessment using GIS. Very few researchers (Hazards Management Group, 1988 and Hobeika, 1988, are among the exceptions) have emphasized the emergency preparedness planning process. Stimulated by Hurricane Andrew, Berke and Stubbs (1989) designed a DSS for hurricane mitigation planning. The work presented here differs in that: (a) this research provides a new approach for the optimal planning of human habitat using a DSS interface; (b) it evaluates multiple controlling variables through the use of GIS-based weighted algorithms; (c) it places more emphasis than has been common in previous studies on land use, geotechnical data, and both bedrock and surficial geology; and (d) it presents a new way to skip over the existing difficulties of combining so many parameters involved in planning decisions, in recognition of the need for an easy way to do this work by professionals without extensive computer experience.

IPDS: INTEGRATED PLANNING DECISION SUPPORT SYSTEM

IPDS has been developed with support from The Integrated Decision Support Group (IDS) at Colorado State University. IDS is intensively working on GIS integrated within mathematical and graphical models.

IPDS: A Decision Support System Oriented to Urban Planning In order to create a planning-purpose spatial decision support system, integration of factual modeling, reasoning and decision making had to be accomplished. IPDS is a computer environmental system that provides functionality to develop specific spatial decision support without the need to write special code to perform some necessary operations. IPDS interface combines individual technologies in a single user-friendly computer environment, where each technology can share the data and control the execution of the overall solution process (Djokic, 1993). Geological hazard zoning and urban planning are examples of problems that are not solvable by conventional mathematics. The multi-criteria nature of geological hazard zoning or urban planning implies that a straight-forward logical or mathematical solution procedure to evaluate these problems does not exist (Fedra and Loucks, 1985).

The integration of GIS and environmental models has been improved by the application programming interface IPDS. This integration provides a common interface and information sharing and transferring between the respective components (Figure 1) using a model built with the "C" programming language.

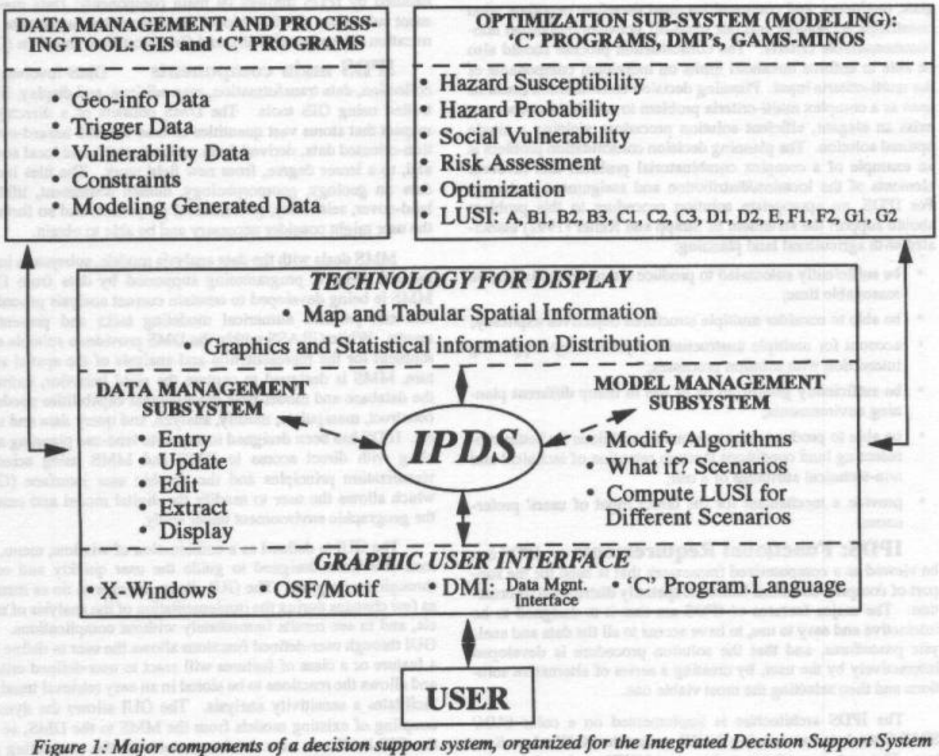


Figure 1: Major components of a decision support system, organized for the Integrated Decision Support System (IPDS). (Modified from Nevo and Garcia, 1993, and Berke and Stubbs, 1989).

To facilitate input of extensive data, the IPDS system is linked with GRASS (CERL, 1992) and with standardized interface. The X-Window System (MIT, 1990), and a number of interface-built tool-kits, make this an efficient integration. IPDS allows the user to select criteria (objectives and constraints), and arbitrarily decide whether the user wants to maximize or minimize them. McHarg (1969) describe some of the criteria that should be considered when setting out to derive an assessment of integrated planning decision and additional geomorphic studies are required to involve hazard assessment such as debris flow, floods, or subsidence hazard susceptibility. It should become obvious from examination of these criteria that they cannot all be measured by the same unit of measurement and that much of the information to be evaluated will be subjective and subject to uncertainty and preconception. The integrated planning consolidation process therefore must accommodate many non-commensurable criteria and objectives. Planners must accept that an individual perception of the land quality or constraints for social development may be quite different from a mathematical or logically derived state assessment. This study considers integrated planning decision as ***an approach of multi-criteria input factors*** to bring stability to urban planning projects.

Ideally, each individual's multi-criteria account statement (set of algorithms in IPDS) at the end of consolidation of the planning assessment should match the starting account goal. This obviously is an unrealistic expectation. Planners, sociologists, engineers, and communities must therefore negotiate what constitutes acceptable and fair trade-off between individual non-commensurable criteria. The consolidation process should also be able to enforce threshold limits on individual components of the multi-criteria input. Planning decision consolidation could be seen as a complex multi-criteria problem to which there does not exist an elegant, efficient solution procedure yielding a single optimal solution. The planning decision consolidation problem is an example of a complex combinatorial problem that involves elements of the location/distribution and assignment problems. For IPDS, an appropriate solution procedure to this problem should support the statement of Strapp and Keller (1992) associated with agricultural land planning:

- be sufficiently automated to produce alternative solutions in reasonable time;
- be able to consider multiple structured objectives explicitly;
- account for multiple unstructured objectives by supporting interaction with solution processes;
- be sufficiently generic to be of use in many different planning environments;
- be able to produce more reasonable solutions by better representing land conditions through retention of technical and non-technical attributes of a cell;
- provide a mechanism for the direct input of users' preferences.

IPDS: Functional Requirements

IPDS can be viewed as a computerized framework that is used for the support of complex decisions based on spatially distributed information. The major features of IPDS are that it is designed to be interactive and easy to use, to have access to all the data and analysis procedures, and that the solution procedure is developed interactively by the user, by creating a series of alternative solutions and then selecting the most viable one.

The IPDS architecture is implemented on a color SUN/SPARC-workstation running UNIX under the X Window System. The system can be ported to most UNIX workstations with a limited amount of effort. The development of IPDS followed two basic approaches: the first one is to develop it from the ground up, by writing the whole code for desired functionality from scratch. This step demands a tight integration with programmers. The second step is the creation and implementation of a GUI by putting together existing applications that provide the necessary tools.

IPDS: Structure

The interactive dialogue subsystem and the display and interactive use components are particularly critical for the effective use of the IPDS since they provide the interaction between user and machine. These features isolate the user from the technicalities of the computer and foster a dialogue based on the user's judgements, rather than imposing the hardware engineer's or computer programmer's discipline upon the user. These models of interaction permit a quick, low-cost examination of alternative solutions as well as the capability to modify assumptions and vary decision criteria. Moreover, the IPDS menu-driven approach was designed with the assumption that the user does not need a strong computer background. The user needs to have the capability to direct the flow of information and modeling effort towards a desired goal. This provides the user with a framework where the user creates individual applications and results using IPDS functionality, but never has to write the functions.

A solution approach to a complex environmental problem is handled by IPDS through its main components: Data management subsystem (DMS), Model management subsystem or optimization subsystem (MMS), and Graphical User Interface (GUI).

IPDS main components

DMS involves data collection, data transformation, map editions, and display, is controlled using GIS tools. The DMS consists of a directory or mapset that stores vast quantities of land use and hazard-evaluation-oriented data, derived from national, state, and local sources and, to a lesser degree, from new field work. The files include data on geology, geomorphology, human settlement, lifelines, land-cover, seismicity, geotechnical properties, and so forth that the user might consider necessary and be able to obtain.

MMS deals with the data analysis models, subsystem implemented using C programming supported by data from DMS. MMS is being developed to emulate current analysis procedures and can perform numerical modeling tasks and present the results. While GRASS within the DMS provides a suitable environment for the representation and analysis of the spatial structure, MMS is designed to capture the cited behavior, including the database and model-base management capabilities needed to construct, manipulate, modify, analyze, and query data and models. IPDS has been designed to expedite land-use planning modeling with direct access to DMS and MMS using scientific visualization principles and the graphic user interface (GUI), which allows the user to modify the digital model and emulate the geographic environment under study.

The GUI is defined as a combination of window, menu, and icon selections designed to guide the user quickly and easily through the program. The GUI allows the user to do as many or as few changes during the implementation of the analysis of models, and to see results immediately without complications. The GUI through user-defined functions allows the user to define how a feature or a class of features will react to user-defined criteria, and allows the reactions to be stored in an easy retrieval trend that facilitates a sensitivity analysis. The GUI allows the dynamic coupling of existing models from the MMS to the DMS, so that the GIS itself acts as a database source to the controlling program. GUI tools provide the user with complete control over the environment in a way not possible in the traditional geo-relational system. And, in this form, the GUI provides the ability to set up a more realistic and effective modeling environment than those that have been possible through simple GIS application. This feature provides the flexibility to interact with the user where the need for the interaction reduces the effort currently demanded by a single application.

While the architecture just described is in fact a collection of diverse, independent software tools, the IPDS interface is assembled in such a way that the analyst always has the impression that he/she is interacting with a single and coherent system. Each of the above-mentioned tasks has been implemented as part of the IPDS system. Each of these components is usually implemented using the already-described different types of technology.

User IPDS provides a framework that orients the user in conducting a planning decision process. The design of the IPDS system includes a wide variety of multi-criteria factors that can be increased, partially avoided, or at least orient the users to better solutions. A logical sequence of steps for the user in IPDS would be:

- Reach agreement on what criteria should be included in the planning decision process.
- Collect data for the above criteria and build a digital database using GIS software (GRASS).
- Examine the theoretical and historical patterns that lead to stability or instability conditions, and modify input data where necessary to meet professional and ethical concerns.
- Calculate and categorize all constraints to be included in an individual hazard assessment, including trigger factors selection such as: probable maximum precipitation (PMP), seismic iso-intensity lines (isoseismal), environmental modifications (land use), etc.
- Promote discussion of algorithms among concerned parties to develop a better and more popular planning decision solution.
- Enforce threshold limits on vulnerability and multi-criteria components. This is implemented by selection or grouping of urban elements such as human settlement, critical facilities and public assembly sites. This leads to a more acceptable risk assessment evaluation and zoning.

Interface Design The Screen Layout of the IPDS interface design, somewhat platform independent is formed by: (1)the ***Menu Bar*** on the top of screen; (2) the ***Control Panel*** on the right side of the screen; (3) the ***Message Box*** and ***Location information*** on the bottom of screen; and (4) the ***Display Window*** in the middle of the screen. Figure 2 shows one of many possible choices. It shows the different shades (colors on the screen) that indicate differences in elevation listed in the legend displayed to the right of the display window.

Hazard Assessment Methodology and Physical factors Geological hazards initially modeled in the study include subsidence, debris flows, and floods. Other models can be run having the data and the algorithm. The dynamic interaction with IPDS for hazard, vulnerability, and risk assessment is based on the assumption that the user has a good background in the required and available information within the database used by the system.

Hazard evaluation inputs are: ***(a) Susceptibility***, determined by a combination of physical factors such as slope (relief), surficial geology (mineralogy, weathering, erodibility and strength), tectonism, geomorphology (morphodynamic processes that modify the landscape and its stability, morphometry), type of soil and geotechnical characteristics, vegetation type and density, land use and land cover, hydrology, constraints, and many others. ***(b) Triggering factors***, determined from the combination of seismicity, precipitation (intensity and duration) evaluated as probable maximum precipitation (PMP), and land use as the human influence on activating disasters through environmental modification.

For each factor, an index of influence is determined through a reference value for every particular site through a specific weight. By multiplying and summing these values through the following equation, a relative Hazard (H) is determined:

$$\text{Hazard} = \text{Hazard Susceptibility} * \text{Trigger(s)} \qquad (1)$$

Therefore, the equation suggested for debris flow hazard (Hdf) evaluation is defined as the product of debris-flow hazard susceptibility (Sdf) times the considered trigger factor, which can be precipitation (Tdf_p), seismicity (Tdf_s), or a combination of both (Tdf_ps).

$$\text{Hdf} = \text{Sdf}*[\text{Tdf\_p} \mid \text{Tdf\_s} \mid \text{Tdf\_ps}] \qquad (2)$$

- **Hazard susceptibility assessment** The natural factors influencing hazards occurrence such as debris flow, can be modified in the field by engineering management activities, and relatively weighted to assess their projection through the IPDS system.

The preceding factors are evaluated and a relative rating of mass instability is given to each mapping unit. The following algorithm, as an example, is suggested to compute and assign a relative weight of each of the primary factors considered as a control on the susceptibility of a particular site to debris flows (Sdf) in the Glenwood Springs urban area (Colorado, USA). It can be interactively modified using the Hazard Susceptibility pull-down menu (Figure 3), pressing the Debris flow option causes the Edit Debris Flow Susceptibility pop-up. To interact with the model the user can modify Modified Algorithm and apply it. Similarly, Hazard can be interactively modified using the Hazard pull-down menu and pop-up window (Figure 4), following Equation 1.

$$\begin{aligned}\text{Sdf} = {} & ((\text{slopedf} * (\text{aspect}*7 + \text{usc\_casag}*4 + \\ & \text{sgmdf}*9 + \text{veg}*8 + \text{hgdf}*5 + \text{shrswell1}*2 + \\ & \text{erosK}*7 + \text{lusess}*3 + \text{wsbuf1}*8 + \\ & \text{femahist2}*10 + \text{isohyaa}*4)/67) + 9)/10 \qquad (3)\end{aligned}$$

Equation 3 (modified from Mejía-Navarro et al., 1994) describes slope susceptibility to debris flows and is basically a weighted average, with the relative weighting for each physical factor indicated by the numerical suffix of that factor. These weighting factors are subjective and may be modified by the operator through the GUI using the IPDS interface model (Mejía-Navarro and García, 1994).

The IPDS interface design is built in a way that the user applies the triggering factors directly through the Hazard pull-down menu, clicking on the hazard of interest. The result is obtained interactively by pressing the button for the user's interest, such as Debris Flow Hazards by both PMP and seismicity as trigger factors, then a pop-up editor comes to the screen.

- **Vulnerability data processing** To assess and be effective in vulnerability reduction for urban planning decision-making, we must be prepared to act within an interdisciplinary frame-work. Also, we must realize that the basic importance of our work is the measure of its projection into the improvement of human life. Therefore, we can say that geological hazard zoning of an area has importance and justification to the extent that we use it in planning decisions. Land use planning includes management of existing human settlement, and orientation of new settlement under 'stable' conditions. Environmental geology and geotechnical engineering are designed to be incorporated into the first steps of planning decisions, to give basic information to develop acceptable conditions for life under most geologic circumstances.

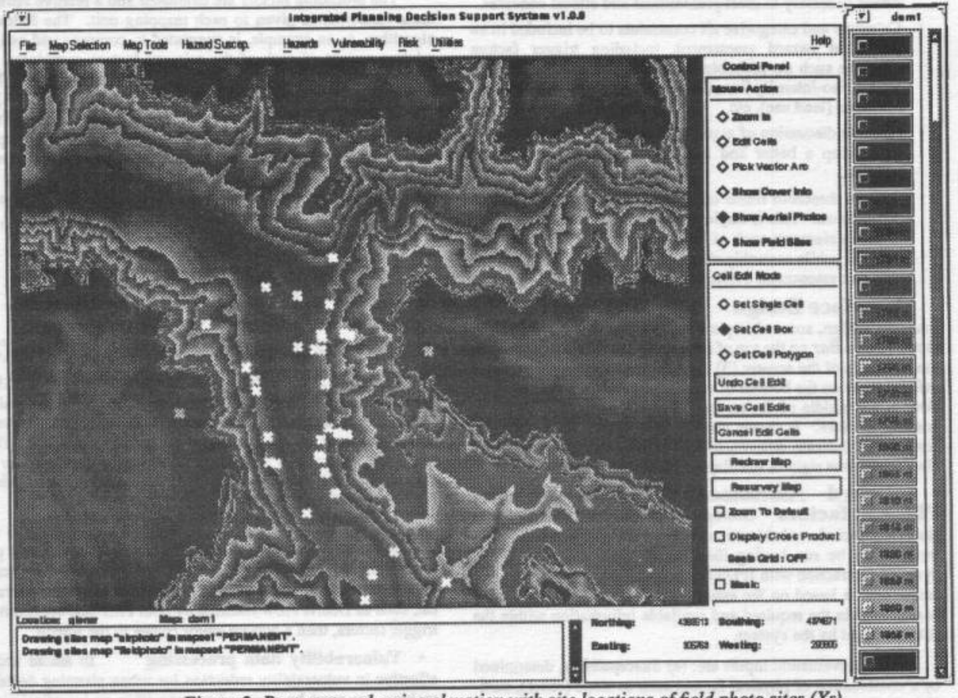
A team of consultants representing all of the disciplines associated with urban planning and development should include soil scientists, geologists versed in geomorphology and environmentalism, civil engineers, hydraulic engineers, design engineers, architects, landscape architects, sociologists, lawyers versed in social conflicts and land-use regulations, transportation engineers, and others. IPDS has been designed to facilitate and promote an easy and fast multi-criteria analysis avoiding a major part of this multi-professional agreement, in order to be more effective in hazard mitigation through productive planning and decision-making. Extensive analysis and definition of land cover and land use by classes should be made, describing density, development approach, traffic circulation and road requirements, flood protection, storm drainage, stream proximity use definition, and utility services. Additionally, extensive studies must be conducted of the preservation of open space available for recreation and time of contingency.

The influencing factors considered for vulnerability assessment and a relative rating of social features response to hazardous events are applied to build the vulnerability algorithm (Equation 4) Land use vulnerability (luseV) assessment is done with consideration of community infrastructure such as building designs and material used in construction and economic zoning, urban infrastructure such as channelization and structural works with special designs to control or mitigate hazards, and social infrastructure such as cultural conditions. Human density is based on census data per block or minimum cell size of the analysis. The lifelines factor considers the buffer area built around the road system network plus water, phone, and electricity lines.

$$\text{vulnerability} = (\text{human\_density}*10 + \text{luseV}*7 + \text{lifelines}*2)/19 \qquad (4)$$

IPDS, through the ***Vulnerability pull-down menu*** (Figure 5) allows the user to modify vulnerability considerations by inserting his/her opinions within the new algorithm which can compute the combination of ecosystem sensitivity (urban infrastructure), economic vulnerability (community infrastructure), and social structure vulnerability (cultural infrastructure).

- **Risk data processing** One particularly complete tool for presenting information on a community's hazard risk is a zoning risk map. Specific risk (Rei) zoning is a procedure of dividing a region into zones that indicate exposure to a specific hazard (Hi) such as debris flows, floods, rockfall, or subsidence. The interest of this type of zone mapping is to estimate the location,



Location: glenar Map: dem1

Drawing sites map "airphoto" in mapset "PERMANENT".
Drawing sites map "fieldphoto" in mapset "PERMANENT".

Northing: 4366513 Southing: 4374571
Easting: 305763 Westing: 293905

Figure 2: Raster map showing elevation with site locations of field photo sites (Xs).

probability, and relative severity of future-probable hazardous events, so that potential losses can be estimated, mitigated, or avoided (Cluff, 1978). Hazard and risk zoning maps provide the basic information for applying land-use planning measures improved by structural and/or non-structural techniques to hazard or vulnerability mitigation. Risk is computed as function of hazard and vulnerability (socioeconomic and political issues):

$$Rei = f(Hi, Ve). \qquad (5)$$

In other words, risk can be understood as the geographical distribution of potential damages affecting elements at risk (Cardona 1988), or as the scenario of social and economic losses. The goals of a risk analysis are to: (1) reduce causal agents, (2) reduce vulnerability, (3) mitigate physical, economic, and mental damage, and (4) improve the process of planning. This study provides a model which calls attention to areas that demand fast and careful attention. This can be done by running different scenarios if conditions of vulnerability and/or hazard have been modified or mitigated by structural or non-structural implementations.

The Risk pull-down menu of IPDS allows the user to selectively evaluate the geographical distribution of potential damages affecting social features, selected when the user computes vulnerability for different types of hazards (Figure 6).

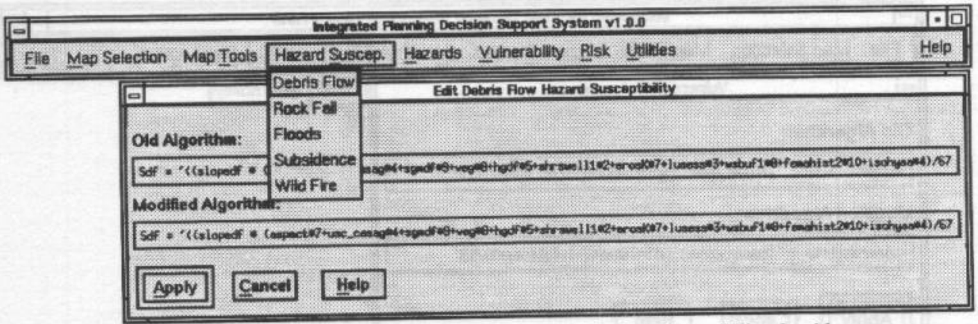
CONCLUSIONS

This DSS called IPDS is built on a decision-making process that community planners often tacitly use now. However, IPDS can help to provide a stronger rationale for the decisions made, particularly in terms of implementation feasibility and costs.

IPDS discusses the potential usefulness of land use planning techniques in relation to technical features such as geologic surficial processes, geotechnical characteristics of ground, environmental conditions, and social aspects. IPDS application allows planners to implement safer emplacements within a minimum time for decision making and the most information available applied.

Acknowledgments Special thanks have to be given to Dr. Ellen Wohl for her comments and revisions to this work and to Integrated Decision Support Group (IDS) for its valuable support to the whole project.

Physical factor abbreviations glossary Abbreviations have been normalized for main entries within algorithms used to compute hazard susceptibilities, triggers, hazards, and risks. These are designed to be close to the normal words, the length of which require abbreviation. The following are the meanings of the input factors in the algorithms described for this study.



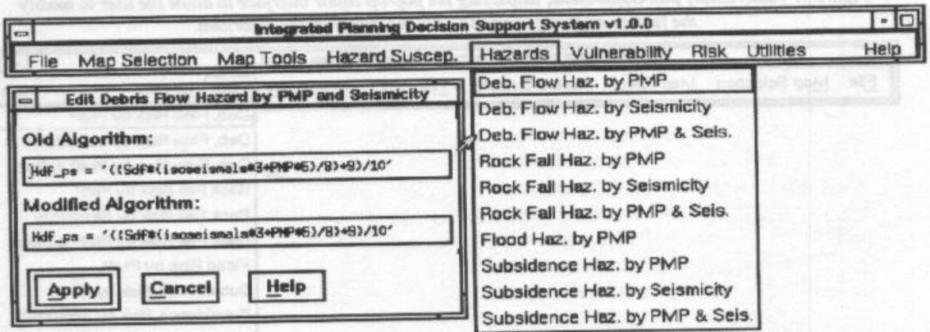
Old Algorithm:

```
Sdf = '((slopedf * (                sag#4+sgmdf#9+veg#8+hgdf#5+shrswell1#2+erosK#7+luess#3+wsbuf1#8+femhist2#10+ischyas#4)/67
```

Modified Algorithm:

```
Sdf = '((slopedf * (aspect#7+usc_casag#4+sgmdf#9+veg#8+hgdf#5+shrswell1#2+erosK#7+luess#3+wsbuf1#8+femhist2#10+ischyas#4)/67
```

Figure 3: Hazard susceptibility pull-down-menu, displaying Debris-flow Susceptibility algorithm pop-up editor



Old Algorithm:

```
}Hdf_ps = '((Sdf*(isoseismals#3+PMP#5)/8)+9)/10'
```

Modified Algorithm:

```
Hdf_ps = '((Sdf*(isoseismals#3+PMP#5)/8)+9)/10'
```

Figure 4: Hazard pull-down-menu, displaying Hazard by PMP and seismicity pop-up editor interface when user wishes to evaluate hazard involving both trigger factors.

slopedf: slope angles from 0°-89° (0%-800%) are divided into 10 classes, with the highest rating (10) given to those angles most characterized by debris flows.

aspect: slope aspect, with 360° = 0° = north-facing, 90° = east-facing, 180° = south-facing, 270° = west-facing.

sgmdf: debris flow susceptibility of surficial geologic material (slope cover). These include different exposed lithologic units - both bedrock and Quaternary deposits - differentiated and reclassified into 10 categories according to their susceptibility to and historic influence on related hazards.

hgdf: hydrologic soil groups used to estimate runoff from precipitation (Harman and Murray, 1992); these are classified based on infiltration rate, water transmission and speed of rise of internal pore pressure.

lusess: a zoning of land use features based on their relative negative influence on slope stability and flooding.

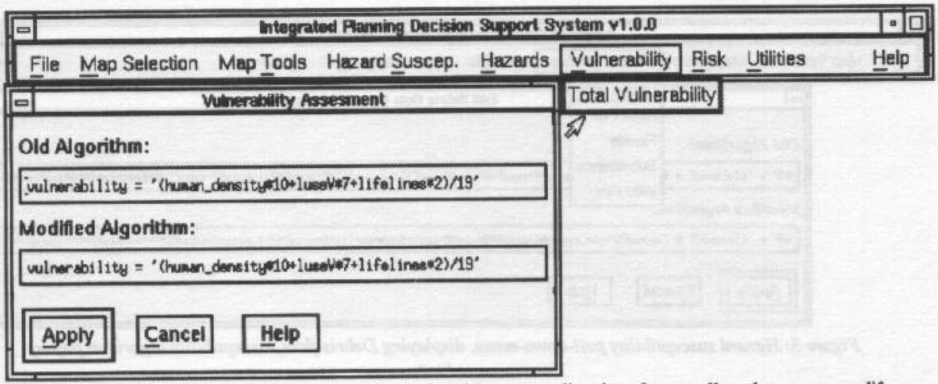
luseV: this factor considers land use reclassification by its vulnerability to be affected by a general natural hazard. This reclassification is based on cultural and economic conditions of the community, on urban infrastructure design of buildings such as zoning of wood versus brick and concrete constructions, urban infrastructure density which blocks or facilitates the passage of debris flows or floods, and proximity to the hazardous areas, and on hazard mitigation infrastructure such as channelizations and structural works with special designs to control or mitigate hazardous events.

femahist2: the data for this factor are the result of a cross-tabulation and reclassification of debris flow records on Quaternary geology maps, historical floods and debris flow records from newspapers during this century, and possible flooding areas estimated with HEC2 (Hydrologic Engineering Center, 1971) evaluations.

isohyaa: isohyets for average annual precipitation from weighting are assigned from 10 for areas with the highest precipitation values in millimeters to 1 for areas with the lowest value of annual precipitation.

Probable Maximum (PMP): isohyetal maps of 25, 50, or 100 year probable maximum precipitation obtained from climate centers. Weighting is assigned to each isohyetal area based on historical record of storms associated with destructive events and the areal distribution of each precipitation intensity on urban areas.

usc_casag: this factor combines (i) regolith texture according to the Unified Soil Classification System (USC), reclassified by grain-size distribution in terms of susceptibility to infiltration and internal structural collapse, and (ii) regolith



Old Algorithm:

vulnerability = '(human_density*10+luseV*7+lifelines*2)/19'

Modified Algorithm:

vulnerability = '(human_density*10+luseV*7+lifelines*2)/19'

Figure 5: Vulnerability pull-down-menu, displaying the pop-up editor interface to allow the user to modify the factors and weighting values in the vulnerability algorithm.

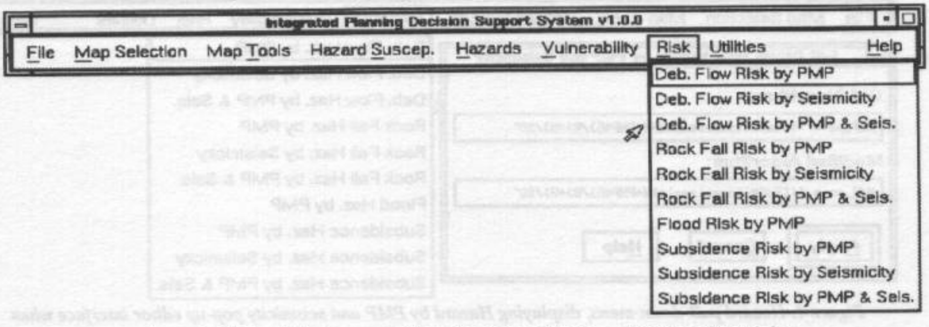


Figure 6: Risk pull-down-menu allows the user a selective estimation of scenarios.

matrix by its proximity to the Casagrande A line (Casagrande classification: Lambe and Whitman, 1969) on a plot of liquid limit versus plastic index.

shrswell: clay content and mineralogy in relation to shrink-swell potential (Harman and Murray, 1992).

erosK: sheet erosion potential using Universal Soil Loss Equation factor K, a measure of the susceptibility of the soil to erosion by water; soils having the highest K values are the most erodible, facilitating debris flows.

isoseismals: when this type of map does not exist, it is built based on seismic waves attenuation behavior empirically assigned to geologic units, in combination with a pattern of radiation of energy from known epicenters and fault planes to create an isoseismal map of expected seismic intensities in specified areas. This can be also considered as a predicted attenuation pattern of seismic waves

lifelines: the buffer area built around the road system network plus water, phone, and electricity lines.

veg: vegetative cover of slope, with categories as calculated for the study area by the Soil Conservation Service (Harman and Murray, 1992).

human_density: this factor is based on population census data per block or minimum cell size of the analysis.

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LINKING GIS AND STORM WATER MODELING FOR EMERGENCY RISK ASSESSMENT

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KEYWORDS: Land use planning, Ground water, Storm water, Floods, Spills, Contaminant transport, GIS, SWMM.

ABSTRACT

Many emergencies involve the deposition of chemical contaminants on land either as a direct event or as a secondary byproduct. GIS can be useful in estimating the initial deposition area. Chemical product attribute data bases can be accessed to determine the degree that the contaminants might be transportable in a water medium. An important issue is to estimate the potential impact of the deposition on surface and subsurface water flows. This is particularly important since millions of people rely on subsurface ground water as their main source of potable water. Thus, a modeling system is needed by planners and emergency managers to assess the potential for short and long term risks to communities due to storm water transport of deposited contaminants. GIS itself cannot provide the complete analysis. A prototype system to assist in estimating the flows of contaminants related to an emergency has been developed by linking an Arc/Info database, Digital Terrain Model, and SWMM the storm water management modeling system. This system also has important planning applications in assessing alternative land development plans for their impact on ground water recharge and management of storm water.

INTRODUCTION:

Emergencies often involve the deposition of chemical contaminants on land as a direct or indirect consequence. The subsequent diffusion of these contaminants through space is often a serious issue as it pertains to placing human, plant and animal species at risk. Modeling of the contaminant diffusion on the land by water as well as air is required to determine areas in need of evacuation and remedial environmental protection. Often ground level contaminant diffusion is achieved by transport through surface water flows and requires analysis that includes storm water modeling and impact analysis in urbanized areas.

Another related class of emergencies relates to urban flooding. Even if there has not been a previous or associated chemical emergency, flood waters resulting from an intense rain storm are often substantially contaminated from "normal" urban contaminants deposited over time on the land, buildings and vegetation. It is claimed (Bryan, 1972) that urban storm water discharges are as contaminated as the effluent discharged from primary sewage treatment facilities in terms of biological oxygen demand (BOD) and its chemical oxygen demand (COD) can be greater than raw sanitary sewage.

Unfortunately the process of urbanization itself reduces an area's hydrological capacitance. This implies that extreme urban storm water and flood events increase in probability as urbanization takes place. This trend is further exacerbated by two other factors. The first is the natural degradation of urban physical storm water management systems due to age, silting, scaling, etc. The second is the increasing climatic variability due to human activity impacts on the biosphere (Jarman, 1993). This appears to be inducing more variability in droughts and intense rainfall events. This in turn may contribute to more frequent and more severe urban flooding.

Both of these classes of emergencies require consideration of the nature and behavior of storm water in the watershed or subwatershed in which the effected area is located. This analysis must also consider the effects of storm water management facilities that have been installed to alter the natural performance of the watershed. Unfortunately, many storm water management facilities that have been installed to reduce local flooding (eg., sewers) operate as very effective means to transport contaminants that can pollute streams, rivers, and water bodies. This can lead to a number of serious environmental problems including, for example, the destruction of sensitive habitats and downstream urban water supplies.

The contaminant transport problem is not simply a surface water flow analysis problem. Due to infiltration of surface water down to subsurface ground water, surface water contamination can begin to compromise the quality of ground water supplies. Since many urban areas draw substantially on ground water for potable water supply, it is important to be able to identify potential ground water impacts of chemical spills and contaminant transport.

APPROACHES TO ASSESSING RISK OF STORM WATER IMPACTS

For the purpose of this discussion, it is useful to consider two general approaches to assessing risk associated with storm water -- GIS and storm water modeling.

GIS and Flood Plain Studies

It is natural that planners and engineers have turned to Geographic Information Systems (GIS) to help assess, manage, and reduce storm water impacts in urban areas. Perhaps one of the most common applications is in mapping flood prone hazard lands. For example, in Ontario, the Conservation Authorities may designate an official flood plane upon which no permanent structures can be built. GIS applications can use Digital Terrain Model (DTM) data referenced to a statistical estimate of an arbitrary flood event to determine, say, a 25 year flood stage and the lands that would be flooded. This approach is based on a separate statistical estimate of the elevation of the surface of a pool of water above the standard flow elevation of streams and rivers associate with a specific severity rainfall of snow melt. The GIS is used to apply the estimated flood elevation against a map of area elevations to find the likely boundaries of the pool's flood area. These statistically based boundaries establish the area flood plane.

Flood plane statistical analysis is based on extrapolating confidence limits of means and deviations of flood histories for nearby flood gauges with adjustments for "nature of land use". Usually, there is not direct computational consideration of future changes due to the process of urbanization nor a detailed analysis of the impact of present and future storm water management facilities. Essentially, the GIS flood plane approach provides a one time analysis of areas possibly susceptible to flooding, but it does not involve itself with analysis of surface or subsurface water flows. While such mapping exercises are very important to designate areas where humans should not be allowed to live or to operate commercial and industrial activities, they are of little value in assessing the potential impact of a spill emergency that requires estimates of the flow of surface and ground water or the flow of flood waters, movement of flood crests, transport of contaminants, etc. If ground water aquifer recharge areas have been identified and previously mapped, a GIS could be useful in identifying and displaying areas of concern in the event of a chemical spill and flooding. However, GIS do not constitute a complete spatial decision support system (Carver, 1991), and current GIS do not have the water flow and analysis tools to provide much beyond the usual map overlay and buffering functions. Newkirk (1993) discusses the requirements for an emergency planning or management GIS. Such a system needs, as well, the capability to calculate storm water flows. Unfortunately, current GIS requires external analysis using a special storm water modeling system or framework.

Storm Water Modeling

A number of major initiatives have taken place over the past two decades to provide computational storm water modeling tools. Their detailed examination is beyond the scope of this paper -- although some of their attributes are useful to consider. In general, most are numerical modeling systems driven by spatial and area parameters and they have no or minor GIS capabilities of their own.

They require a study area (i.e., a watershed or subwatershed) to be decomposed into a series of mutually exclusive and distinct analysis subunits. Storm water modeling is applied to each analysis unit with flow amounts being transferred from subunit to subunit as appropriate. Most modeling systems deal with flow quantity estimates for single event scenarios -- however some allow for water quality and continuous event studies. As a storm water model is being structured, it can benefit from GIS analysis to help define the appropriate subunits for analysis. In addition, GIS can provide important location and performance information about any storm water management facilities that could impact on modeling results.

Like many other computational models, storm water models are very dependent on the correct parameters. Once the parameters have been set, the user provides one or several hydrographs that describe the expected precipitation over time. The modeling system calculates hydrographs (in graph and tabular format) that describe the resulting performance at specified points. Most modeling systems have been influenced by one or both of the following methods: SCS and SWMM.

The Soil Conservation Society (SCS) Method.

The United States Department of Agriculture, Soil Conservation Service, has developed a storm water quantity model (usually called the SCS model) that draws upon extensive SCS soils data (USDA/SCS, 1975). It is a popular system or basis for customized systems due to its relative simplicity. McCuen provides a helpful description of its nature and application (McCuen, 1982).

It requires a decomposition of an area under study into suitable subareas to which the model is applied. The modeling framework is designed to be sensitive to an association between:

- soil characteristics, land form and practices, and
- land cover and land use

in each subarea. A table of associations between these two aspects provide a "curve number" (designated CN -- see McCuen, 1982, for tabular examples) that becomes part of the computation. Tabular entries relate, in part, to the well developed and widely accessible Soil Conservation Service soils maps. If the subareas are relatively homogenous, the determination of the appropriate curve number could be obtained from a GIS by an appropriate table driven classification. In cases where there are differences in the associations within a subarea, the method allows for a lumped estimate of CN that is derived by means of weighted averages of the corresponding area covered. The key surface water flow equations in the basic model are (McCuen, 1982):

$$I_E = \frac{(P - I_a)^2}{P - I_a + S}$$

and

$$S = \frac{1000 - 10CN}{CN}$$

When:

Symbol	Meaning
I_E	Accumulated direct runoff (rainfall excess)
P	Accumulated precipitation
I_a	Initial surface storage
S	Maximum potential retention
CN	Curve number (from table)

A brief inspection shows that the information required to operate the key equations is relatively straight forward. Accordingly it has proved a relatively easy framework to implement in computer programs. Many other equations are included in the SCS modeling system. They include equations for modeling channelized flow of the resulting runoff water and estimates of ground infiltration. The SCS method has shown good accuracy in small urban water sheds (Berry and Sailor, 1987), and has been effective at "representing the infiltration characteristics of a watershed" (Sheaffer, *et al.*, 1982, pg. 121). However, it seems to be sensitive to the number of subunits used in a study. Too large a number of subunits appears to lead to an overestimate of flows (Berry and Sailor, 1987). The method is not adequately developed for calculating water quality (i.e., the transport of chemical contaminants) or the influence of storm water management facilities.

The Storm Water Management Model (SWMM)

The Storm Water Management Model is a very large integrated model jointly developed in the early 1970's by several contractors with support from the US Environmental Protection Agency. It consists of four major computation subsystems (Runoff, Transport, Extended Transport, Storage & Treatment) plus a number of computation "service" components. Its main users are specialists (i.e., consulting engineers and researchers). Since its inception, it has experienced continual development and update. Various software implementations are in current use.

SWMM provides a means to model both quantity and quality (up to 10 contaminants) of storm water. Special processing is available for snow accumulation, snow pack, and snow melt. It can process the effects of various storm water management facilities. This includes the ability to include a network of sewers of several kinds and sizes. In addition, it provides for upper and lower ground water (i.e., subsurface zones) and infiltration calculations.

Similar to other models, it requires the user to desegregate a watershed or subwatershed into a set of mutually exclusive and distinct subunits for analysis. The calculation of storm water surface flow is based on a non linear reservoir excess flow according to the following equations (Irvine *et al.*, 1994):

$$\frac{dV}{dt} = A \cdot I_E - Q$$

and

$$Q = W\left(\tfrac{149}{n}\right)\cdot\left(D - D_p\right)^{1.67}\cdot S^{0.5}$$

when:

Symbol	Meaning
V	Volume of water on the surface
I_E	Excess rainfall rate
A	Area of the subunit (subcatchment)
Q	The outflow rate (after Manning)
W	Width of subunit (subcatchment)
D	Water depth in reservoir
D_p	Depth of surface reservoir storage
S	Slope of subunit (subcatchment)

There are many additional equations related to infiltration, contaminant transport and decay. Due to its many capabilities, SWMM requires the user to define a very large set of performance parameters to condition a model run. Table 1 lists this author's summary of the basic number of parameters required by the runoff calculation system. Note that some of these can require multiple specifications.

Table 1: SWMM Basic Model Parameters

Group	Parameters	Repeat Max	Purpose
1	8	1	System parameters
2	3	1	Output control
3	5	1	Time control
4	2	1	Continuous simultion -- subcatchments
5	10	1	Snow input
6	5	1	Wind speeds
7	5	1	Snow depletion on impervious
8	5	1	Snow depletion on pervious
9	var	1	Air temps
10	var	1	Precipitation control hyetograph input
11	var	1	Evaporation rates
12	10	100	Chanel and pipe data
13	4	var	Flow control structures
14	17	200	Subcatchment definitions
15	7	100	Ground water subcatchment definitions
16	14	1	Ground water flow parameters
17	11	200	Snow input by subcatchment
18	16	200	Snow input by cubcatch. (continuous sim.)
19	11	1	Environment context control
20	8	var	Land use descriptions
21	21	10	Contaminant constituents
22	7	1	Erosion control section
23	10	200	Subcatchment surface quality
24	5	1	Print control

SWMM's ability to deal directly with storm water quality as well as quantity, and its ability to model the effects of storm water control infrastructure make it potentially important to emergency planning and management applications. However the very large number of area dependent parameters limits its usefulness unless the user is a SWMM modeling expert. An automated means to help set model parameters is required.

Difficulties In Emergency Planning and Management Use of Storm Water Models

Problems in using current storm water modeling systems for emergency planning and management as well as for "what if" regional and urban planning studies include: establishing the proper model parameters, providing appropriate and up to date data, determining proper study area disaggregation, requirement for trained operators, possible requirement for custom computer programming, and cumbersome linkage to GIS and emergency information systems. It is important to link GIS and storm water modeling in an integrated computing framework.

LINKING GIS AND STORM WATER MODELING

An integrated system to link GIS and storm water modeling is under development as part of a large multidisciplinary project addressing issues of sustainability in an urbanizing watershed. Its main purpose is to provide a general purpose modeling environment that can assist with questions related to urban and regional development and emergency planning and management. The main objective is to use computing capability to allow planners and emergency managers to conduct detailed "what if" studies based on high quality background analysis and well developed municipal and regional data bases.

A schematic diagram of the system is seen in figure 1. The system implementation is based on major software application systems and the development platform is an IBM RS6000 networked Unix system. There are three main major computational components: a full feature GIS (Arc/Info), a full capability storm water modeling system (SWMM), and a process manager and knowledge base system (RAISON).

Rather than develop a special purpose limited capability built in GIS, the major commercial GIS, Arc/Info, was chosen to be linked with the Knowledge Base Manager. This provides the project with a full range of vector based GIS processing (eg., overlay, buffering, interpolation, etc.), and access to substantial data bases of regional and municipal information.

In spite of the effort required to determine the parameters of the SWMM storm water modeling system, it was chosen to be linked with the Knowledge Base Manager because it provides: both quantity and quality modeling of storm water, ability to deal with ground water and infiltration, and the effects of existing or proposed storm water management facilities. Thus the project includes an important subproject that is examining ways that a knowledge base system can invoke data and analysis capabilities in the Arc/Info system to set the parameters for SWMM analysis.

The RAISON system is a recent joint development by Dr. David Swayne in the Department of Computer and Information Science at the University of Guelph and the Canadian Centre for Inland Waters. Its main features are a georeferenced mapping display and statistical capability plus ID3 -- a rule based expert system shell with an effective programming language. RAISON's knowledge base processing and programming language capability facilitates developing the necessary control scripts to send to Arc/Info and SWMM. It provides a menu system and graphical user interface that can be readily tailored to develop prototypes for user/system interaction.

System development is being tested on a moderate scale case study of the Laurel Creek Watershed where there has been a very recent large scale consulting study related to future urban development. (Laurel Creek is a subwatershed of the Grand River Watershed). This provides the project with extensive data sets, some detailed hydrographic studies, and a link to several other active studies (including land use and vegetation studies). This will provide an opportunity to test automated processing against independent consultant studies.

Two major graduate research themes are involved: (a) contaminant transport in surface storm water and how this is influenced by changing individual building lot and subdivision design, and (b) ground water infiltration as it relates to alternative approaches to subdivision design.

All necessary data sets are now stored in the GIS. Current development activity is related to developing the SWMM parameters and the RAISON process control scripts to develop and manage GIS and storm water analysis.

This should provide an effective system that enables emergency planners, municipal managers and engineers to address storm water issues.

ACKNOWLEDGMENTS

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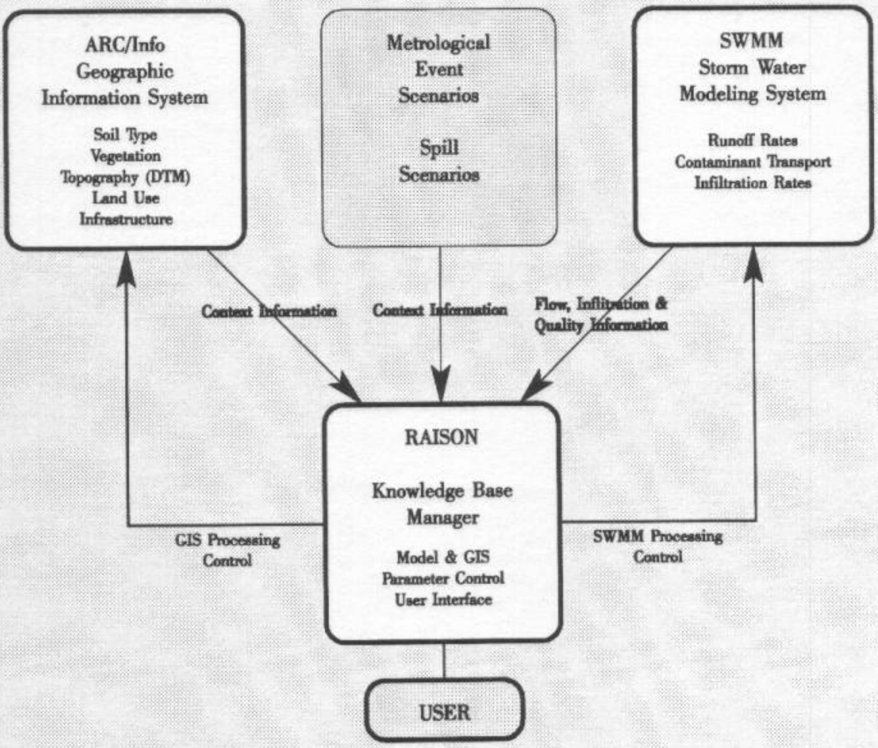
Figure 1: GIS & Storm Water Modeling for Planning



TIEMEC '95

APPLICATIONS

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Technology Transfer for Emergency Management

Chair:
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SEISMIC SAFETY OF NUCLEAR POWER PLANTS IN EUROPE AND THE MEDITERRANEAN REGION AT LARGE

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KEYWORDS: Seismic safety, risk evaluation, nuclear power plants, technology transfer.

ABSTRACT

Nations that have launched large-scale electro-nuclear programs (such as the United States and France), in conjunction with the International Atomic Energy Agency (IAEA), have both implemented research & development programs targeting the reliable evaluation of seismic hazard and drawn up regulatory documents making use of the knowledge gained. Other countries envisioning a move towards nuclear electric technology have the opportunity of benefiting from the experience already acquired by the aforementioned countries, notably in this critical area. As the nuclear industry is not currently in a phase of expansion, most of the case studies for which IAEA expertise is sollicited concern plants undergoing a reassessment procedure, particularly in Eastern Europe. The prime motivation for this has been the need to ascertain how well the criteria and standards underlying the seismic safety of such facilities measure up to those generally accepted in international practice.

INTRODUCTION

The seismic safety of nuclear installations has become a subject of concern for various national and international institutions, notably the International Atomic Energy Agency (IAEA). The first countries to make extensive use of atomic energy to generate electricity (the United States and France, in particular) have, over past decades, been conducting research and development work aimed at gaining a better understanding of seismic hazard, in order to establish methods of seismic protection and to define criteria and standards.

Seismic safety issues generally involve two major components: those related to the derivation of design-basis parameters and those concerning the seismic capacity of structures, equipment, and distribution systems. The various steps entailed in evaluating seismic hazard result in determining levels of seismic reference motion to be taken into account in the anti-seimsic design of facilities. Although the first countries to develop nuclear power technology have codified their own regulations in this field, IAEA, in the framework of its own program (IAEA Safety Codes & Guides, NUSS program), has issued guides to aid in ensuring seismic safety, notably 50-SG-S1 (Rev. 1), which deals specifically with determining seismic motion. The guide specifies the stages of a procedure that defines two levels of reference motion, termed *SL1* and *SL2*.

A key element, fundamental to such an evaluation, is the compilation of exhaustive and uniform data in geology, in historical (particularly in Old World countries) and instrumental seismicity, in geophysics, and in any other branch of earth science capable of affording insight in the matter. The IAEA guide emphasizes the necessity of having the data be uniform, sanctioned by quality assurance, so a seismotectonic model can be elaborated for the region under investigation.

Under the aegis of the IAEA, a working group was formed in 1988, composed of representatives of countries around the Mediterranean basin; it has been endeavoring to establish the status of existing data and to make sure these are processed in a uniform fashion. This working group lays the groundwork for fruitful contacts between countries already experienced in this field and others that are only now embarking upon the siting process of a nuclear facility.

The proximity of an active, or worse yet, of a *capable* fault (one liable to generate surface rupture in the event of an earthquake) is highly prejudicial to the siting of a nuclear facility. In order to establish whether such a fault is present on a given site, various techniques in geology and seismology, as well as other branches of geophysics, are called on. The installation and operation of a seismic monitoring network centering around a postulated site, as recommended by IAEA (cf. "Application of Microearthquake Surveys in Nuclear Power Plant Siting" - IAEA-TECHDOC-343), constitutes an excellent framework for bipartite cooperation. An instance of such a cooperation is one between France's Institut de Protection & de Sûreté Nucléaire (IPSN) and the Tunisian utility, Société Tunisienne d'Électricité & du Gaz (STEG). IPSN has taken an active part in the interpretation of the results obtained by the network and has provided specialized training for some STEG personnel in this area.

The seismic safety of nuclear power plants in Eastern Europe has been the object of renewed attention in the wake of the recent political and social changes. The primary motivation for this has been the need to compare the criteria, standards, and methods underlying seismic safety in Eastern European nuclear power plants with those generally accepted in international practice. Seismic hazard assessment has been recently at issue at most of the sites because of the differences in the methods employed when the site investigations were being carried out prior to construction. Although most Eastern European nuclear power plant sites can be rated as low-to-medium seismicity sites, deficiencies in the tectonic and seismic data base as well as in the methods used in the 1970's have given rise to hazard re-evaluation programs. The results of the new studies consistently indicate that the design-basis ground motion parameters had been underestimated, sometimes by a considerable margin.

The involvement of IAEA and its experts from member states in the seismic safety issues of Eastern Europe has been substantial through national, regional, and extra-budgetary projects. Seismic safety review missions have visited nuclear power plants in Armenia, Bulgaria, the Czech Republic, Hungary, Poland, the Russian Federation, Slovakia, Slovenia, and Ukraine within the past five years. The experience of these five years has recently been channeled into a Coordinated Research Program entitled "Benchmark Study for the Seismic Analysis and Testing of WWER-type Nuclear Power Plants." The program has twenty-three participating institutions from fifteen countries and concentrates on WWER-440/213 and WWER-1000 plants. Paks Nuclear Power Plant in Hungary and Kozloduy Nuclear Power Plant (Units 5/6) in Bulgaria are prototype plants for this project. Tables 1 and 2 present general and seismic characteristics, respectively, for nuclear power plants in Eastern Europe.

Certain other countries have initiated nuclear projects that are scheduled to begin operation by the end of the century or shortly thereafter. These countries - Portugal, Morocco, Tunisia, Pakistan, and Indonesia, among others - have likewise profited from close cooperation with IAEA and its experts. The data collection effort, but also the exchange of knowledge and working procedures in the area of seismic risk assessment, not only lay a reliable groundwork for the nuclear projects directly concerned, but furthermore are of value to urban planners in protecting cities and populations in the event of earthquake. Concretely, they contribute such basic tools as historical earthquake catalogues, seismotectonic zoning studies, regional attenuation laws, and microzonation maps.

The purpose of this paper is to provide an overview of the various programs initiated by IAEA and experts from member states that deal with the seismic safety of existing and future NPP's, notably in Eastern Europe and Mediterranean countries.

SEISMIC SAFETY REVIEW SERVICES

Member states can obtain the advice of interdisciplinary teams of independent experts on site and safety aspects of planned or existing nuclear power plants (NPP's). Site safety and external hazard reviews may cover a broad range of disciplines - for example geology, seismology, hydrology, vulcanology, meteorology and tectonics - and the teams also look into such matters as the local population distribution and the impacts of possible man-induced events (e.g. an aircraft crash). When the focus is on the assessment of the seismic capacity of the plant, the review team includes experts in structural mechanics with experience of seismic plant walkdowns and the design of NPP structure, system, and component upgrades to resist seismic effects.

As only a few sites are at present being investigated with a view to the construction of new NPP's, the requests made by member states in recent years have been mainly for reassessments of the safety of existing plants. In particular, the Secretariat has been receiving requests for seismic safety review missions to the sites of WWER-type NPP's (see Table 3). These reviews focus on two major aspects, i.e. the adequacy of the design-basis seismic input and the seismic capacity of the plant structures, equipment, and distribution systems. For Eastern European nuclear power plants, it was established that the original design-basis seismic input values were consistently underestimated.

Another conclusion which has emerged from such missions is that WWER-440/230 and 440/213 plants (and also RBMK plants) do not have inherent structural resistance to the types of loads associated with earthquakes (and with similar external events). This is due to the fact that in such plants only the pressure boundary (i.e. the equipment that operates under pressure) is designed to withstand extreme loads; the superstructures housing the reactor, turbines, and emergency diesel generators are designed as normal industrial buildings with large spans and very little cross-bracing to take lateral (i.e. earthquake-induced) loads and are constructed in such a way that they have relatively low ductility. When the re-assessed seismic design basis acceleration is low (e.g. ~ 0.1g), minor structural strengthening may be sufficient; when it is even only slightly higher (0.2-0.3g), however, complex and expensive structural upgrading becomes necessary.

Following seismic safety review missions, the seismic upgrading of structures, systems, and components at the Kozloduy NPP (Bulgaria), the Bohunice NPP (Slovakia), and the Paks NPP (Hungary) is under way. In Armenia, the geological and seismic hazards associated with the site of the Medzamor NPP, shut down after the 1988 Spitak earthquake, are being re-assessed. As to the NPP's not of Soviet design, seismic upgrading is in progress at the Karachi NPP, Pakistan, which went into service in 1972. Also in Pakistan, a seismic design review is being conducted of the Chinese-designed 300-MW(e) NPP under construction at Chashma, use being made of the experience gained in seismic reassessments of various existing NPP's.

BENCHMARK STUDY FOR THE SEISMIC ANALYSIS AND TESTING OF WWER-TYPE NPP'S

An overview of a procedure which is recommended to assess and enhance the seismic capacity of existing WWER reactors is provided. The major focus of this procedure is to make a cost-effective process available which will allow needed modifications to be prioritized and implemented in a timely manner, using the realistic assessment of responses and capacities. Major technical elements of this procedure are:

1) The identification of the most critical systems, components, and structures needed for safe shutdown and to maintain safe shutdown;

2) The evaluation of as-built conditions through data-gathering activity such as review of design drawings and construction specifications and detailed walkdown;

3) Realistic assessment of plant response and capacity evaluations for developing acceptance criteria and designing cost-effective fixes; and

4) Functional qualification of active mechanical and electrical components through use of generic test data applicable to all WWER's, plant-specific tests and earthquake experience data.

This procedure is sub-divided into three major categories: equipment, structures, and distribution systems, for prioritizing design and implementation of needed fixes. Some fixes, such as anchorage upgrades, are easily identifiable and could be designed for conservative seismic demand. This demand would be confirmed after a detailed plant response analysis is completed. Other fixes involving major structural elements or complex load paths would necessitate realistic response evaluations as well as capacity evaluation to design cost-effective fixes. The aim of the assessment is to show that the plant can withstand a Level SL2 earthquake without giving rise to a Level V accident (on the INES Scale). This will be interpreted as ensuring that service condition D (as defined by ASME), or the equivalent, is not exceeded. If this is not possible, modifications will be identified that, when implemented, will prevent the occurrence of the Level V accident. It should be noted that a Level V accident is defined as an "accident with off-site risk."

After identification and classification of systems to be considered, the seismic input, soil data, acceptance criteria and loading combinations are established. Considerable effort and decision-making is required to arrive at this point. In general, the seismic input is determined using the principles and methods established for new sites and plants (see e.g. IAEA 50-SG-S1, Rev. 1991). The only difference might be due to the "lifetime" of the plant when the input is calculated on a probabilistc basis. This is generally shorter for existing plants (if life-extension is not envisaged) and may lead to somewhat lower design values. The major difference with the seismic design of a new plant would be related to acceptance criteria, which would make use of existing safety margins to the fullest extent possible. Beyond the evaluation of the situation and setting up of criteria, the methodology is specific depending on the plant item in question, i.e. structures, distribution systems, and equipment.

Special emphasis is placed on the "easy-fixes" resulting from the structural evaluation of distribution systems and equipment, which, when implemented, may increase seismic safety most cost-effectively. This has already been observed in the seismic upgrading of the Kozloduy NPP, Units 1-2, for which IAEA has provided continuous support through review services, including the preparation of the Terms of Reference (TOR) for the seismic upgrading program. The TOR specifies four phases for the seismic upgrading of the Kozloduy NPP, Units 1-2, each phase increasing the safety level by implementation of "easier" fixes and assessing the seismic capacity of more complex items systematically. This eventually leads to the attainment of the seismic safety goal within a specified time frame.

For the Paks NPP, a Terms of Reference document has recently been prepared with the objective of unifying the acceptance criteria. The first step of the phased upgrading program comprises the so-called "easy fixes." These were identified using the following criteria:

1) The item must be fixed to ensure the required margin;

2) The technical solution and cost of the fixes should depend only slightly on the limited variation of the earthquake level;

3) The fixes should be relatively easy to carry out and capable of being effected during planned outages.

The actual benchmarking of analysis and testing is mainly envisaged for structural systems in the beginning of the project.

Full-scale dynamic testing of the reactor structures of both the Kozloduy (Unit 5 or 6) and Paks (Unit 1, 2, 3 or 4) Nuclear Power plants has been slated for the period 1994-1995. Although some testing has already been performed on these structures on previous occasions, a more systematic and integrated approach to testing is envisaged for the benchmark study. Preparations for full-scale dynamic testing of the Paks NPP are currently under way.

The Coordinated Research Program on the benchmark study involves twenty-three institutions from fifteen countries. This is a three-year program initiated in 1993. Two research coordination meetings have been held so far, the first at the Paks NPP in September 1993 and the second at the Kozloduy NPP in June 1994.

Table 1. Nuclear power plants in Eastern Europe (selected).

Plant	*Country*	*No. of Units*	*Power/Type*	*Status*
Kosloduy	Bulgaria	4	440/230 WWER	In operation
Kosloduy	Bulgaria	2	1000 WWER	In operation
Belene	Bulgaria	2	1000 WWER	Construction stopped
Cernavoda	Romania	4	660 Candu	Under construction
Krsko	Slovenia	1	630 PWR	In operation
Paks	Hungary	4	440/213 WWER	In operation
Bohunice	Slovakia	2	440/230 WWER	In operation
Bohunice	Slovakia	2	440/213 WWER	In operation
Mochovce	Slovakia	2	440/213 WWER	Under construction
Dukovany	Czech Republic	2	440/213 WWER	In operation
Temelin	Czech Republic	2	1000 WWER	Under construction
Medzamor	Armenia	2	440/230 WWER	Construction stopped

Table 2. Seismic design basis (*SDB*) for NPP's in Eastern Europe (selected).

Plant	*Original SDE (PGA)*	*Re-assessed SDB (PGA)*	*Upgrading Status*
Kozloduy	No explicit design	0.2 g	Continuing in first four units
Bohunice	No explicit design	0.25 g (continuing)	Continuing
Mochovce	0.05 g	0.1 g (continuing)	Continuing
Belene	0.1 g	Continuing	Continuing
Cernavoda	0.15 g	No re-assessment	Continuing
Paks	No explicit design	0.35 g (continuing)	Continuing
Krsko	0.3 g	Continuing	Continuing
Temelin	0.06 g	0.1 g	Continuing
Medzamor	0.1 g	0.4g (continuing)	Continuing

Table 3. Engineering safety review services related to site and external hazards:

S	Review of site investigations for all disciplines involved.
S-F	Follow-up mission of previous reviews of site investigations
SI	Review of investigations for determining the seismic input parameters specific to the site
SI-F	Follow-up mission of previous reviews of seismic input definition
SC	Review of seismic capacity and necessary upgrading of systems, structures, and components (SCC) of the plant
SC-F	Follow-up mission of previous reviews of seismic capacity and upgrades of SSC
W	Workshop
WP	Review of work plans and technical procedures for the site and seismic safety assessment
B	Activities related to benchmark project for seismic safety of WWER-type NPP's.

Year 1989

No.	*Type*	*Country*	*NPP/Location*	*Date*	*Plant Type*
1	S	Iraq	Site survey	February 89	–
2	S	Tunisia	Site survey	April 89	–
3	S	Indonesia	Muria	May 89	(not defined yet)
4	S	USSR	Gorki DHP	June 89	
5	S	Morocco	Sidi Boulbra	December 89	–

Year 1990

No.	*Type*	*Country*	*NPP/Location*	*Date*	*Plant Type*
6	S	Poland	Zarnowiecz	March 90	–
7	S	CFSR	Temelin	April 90	WWER-1000
8	S	Iraq	Near Tikrit	May 90	–
9	S	Bulgaria	Belene	June 90	WWER-1000
10	S	Bulgaria	Kozloduy	June 90	WWER-440/230-1000
11	SC	Romania	Cernavoda	September 90	PWR 600
12	S	Pakistan	Chashma	November 90	PHWR 300
13	SC	Romania	Cernavoda	December 90	PHWR 600

Year 1991

No.	*Type*	*Country*	*NPP/Location*	*Date*	*Plant Type*
14	S	Indonesia	Muria	January 91	(not defined yet)
15	S	Slovenia	Krsko	March 91	PWR 600
16	SC	Bulgaria	Kozloduy	April 91	WWER-440/230
17	W	Bulgaria	Kozloduy	May 91	WWER-440/230
18	S	Tunisia	NPP site survey	May 91	–
19	S	USSR	Crimea	June 91	WWER-1000
20	W	Romania	Cernavoda	September 91	PHWR 600
21	W	CSFR	Temelin	September 91	WWER-1000
22	SC	CSFR	Bohunice	September 91	WWER-440/230
23	S	Tunisia	Site survey	November 91	–
24	WP	Indonesia	Muria	December 91	(not defined yet)
25	WP	CSFR	Temelin	December 91	WWER-1000

Table 3 (cont.).

No.	*Type*	*Country*	*NPP/Location*	*Date*	*Plant Type*
			Year 1992		
26	SI	Bulgaria	Kozloduy	February 92	WWER-440/230
27	W-WP	Slovenia	Krsko	March 92	PWR 600
28	SI	Bulgaria	Kozloduy	April 92	WWER-440/230
29	SC-F	CSFR	Bohunice	May 92	WWER-440/230
30	SI-SC	Armenia	Medzamor	May 92	WWER-440/230
31	S-F	CSFR	Temelin	June 92	WWER-1000
32	W-S	Malaysia	Site survey	June 92	–
33	SC	Bulgaria	Kozloduy	August 92	WWER-440/230
34	SC	Pakistan	Chashma	August 92	PWR 300
35	S	Indonesia	Muria	September 92	(not defined yet)
36	SI	Slovenia	Krsko	October 92	PWR 600
37	S-F	Indonesia	Muria	November 92	(not defined yet)
38	SC	Bulgaria	Kozloduy	November 92	WWER-440/230
39	S	Tunisia	Site survey	December 92	–
			Year 1993		
40	S-WP	Indonesia	Muria	February 93	(not defined yet)
41	SI-F	Bulgaria	Kozloduy	February 93	WWER-1000, 440/230
42	SC	Pakistan	Chashma	March 93	PWR 300
43	S-F	Czech Republic	Temelin	April 93	WWER-1000
44	SC-F	Slovakia	Bohunice	April 93	WWER-440/230
45	S-MP	Indonesia	Muria	April 93	(not defined yet)
46	W	Pakistan	Chashma	May 93	PWR 300
47	SC	Pakistan	Kanupp	May 93	PHWR
48	S	Croatia	Site survey	June 93	–
49	SC	Russian Fed.	Smolensk	June 93	RBMK
50	W	China	(generic)	July 93	–
51	S-F	Indonesia	Muria	July 93	(not defined yet)
52	SI-B	Hungary	Paks	September 93	WWER-440/213
53	WP	Armenia	Medzamor	August 93	WWER-440/230
54	SI	Bulgaria	Belene	September 93	WWER-1000
55	SI	Slovakia	Bohunice	October 93	WWER-440/230-213
56	SI	Slovakia	Mochovce	October 93	WWER-440/213
57	SI-WP	Armenia	Medzamor	November 93	WWER-440/230
58	S	Indonesia	Muria	November 93	(not defined yet)
59	S	Morocco	Sidi Boulbra	November 93	–
60	SC	Hungary	Paks	December 93	WWER-440/213
61	SC-F	Pakistan	Chashma	December 93	PWR 300
62	W	Turkey	Akkuyu	December 93	(not defined yet)

TECHNOLOGY TRANSFER DURING THE "MIDDLE GAME" OF THE INTERNATIONAL DECADE FOR NATURAL DISASTER REDUCTION

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KEYWORDS: Technology transfer, IDNDR, STAPLE

ABSTRACT

This paper describes the urgency for and the importance of technology transfer during the remainder of the International Decade for Natural Disaster Reduction (IDNDR). Eleven case histories are cited to illustrate the types of activities involving technology transfer that every nation can undertake.

INTRODUCTION

The concept of the IDNDR was proposed in July 1984 by Dr. Frank Press at the Eighth World Conference on Earthquake Engineering. After several years of planning, on December 22, 1989, 155 nations cosponsored United Nations Resolution 44/236 which called for concerted national and international actions during the 1990;s to reduce the loss of life and economic losses from earthquakes, volcanic eruptions, landslides, floods, severe storms, wildfires, tsunamis, and droughts.

The IDNDR is now in the "middle game." Unlike the "opening" game in 1990 and the "end game," the middle game of the IDNDR is more complex because of the following factors:

1. Considerable resources from natural disaster reduction have been used up during the first 5 years of the decade and cannot be recovered or reallocated.
2. Many initial courses of action (strategies) are no longer viable because of limitations in time and space on human fiscal resources.
3. The focus has shifted from "what one would like to accomplish" (i.e., the vision in 1990) to "what one can actually accomplish during the remaining 5 years" (i.e., reality in 1995).
4. The complexities of regional/national needs are greater than ever because of the large number of recent, devastating natural disasters and the threat of others. Recent disasters include:

-- Earthquakes in Iran, Turkey, Egypt, the Philippines, Japan, Colombia, India, and the United States;
-- Volcanic eruptions and/or threatening eruptions in Hawaii, Alaska, the Philippines, and Zaire;
-- Floods in China, United States, and Italy;
-- Droughts in Africa;
-- Tsunamis in Japan, Indonesia, and Nicaragua; and

- Severe storms in the Philippines, United States, and Mexico.

5. The "end game" of the IDNDR has not yet been defined.

TECHNOLOGY TRANSFER

The May 1994 World Conference In Yokohama, Japan provided a basis for strategic planning during the middle game of the IDNDR. The 3,000 delegates to the conference called for a renewed emphasis on regional technology transfer to solve local problems. Countries having data, information, experience, and know how were urged to assist neighboring and developing countries needing a greater technical capacity.

The goal is to reduce community vulnerability to natural hazards (i.e., eliminate flaws in planning and development). These flaws make communities throughout the world susceptible to socioeconomic impacts from: floods, landslides, wildfires, severe storms, earthquakes, tsunamis, droughts, and volcanic eruptions.

The potential for disaster is greatest when communities are located:

--in or adjacent to seismogenic zones capable of generating damaging earthquakes,
--along coasts where hurricanes, cyclones, typhoons, storm surges, or tsunami flood waves strike,
--in flood plains subject to inundation from riverine floods or flash floods,
--in regions prone to tornadoes,
--near active volcanoes,
--on unstable slopes susceptible to landslides triggered either by meteorological or seismological sources,
--along wilderness/urban interfaces susceptible to wildfires, and
--in regions prone to drought episodes.

Reduction of community vulnerability to natural hazards requires a long-term process to change the hazard-, the built-, and the policy-environments of the community (fig. 1). These changes take time because the process depends on actual experiences with natural disasters and on current and ongoing research to deepen understanding of the six forces (called STAPLE forces in this paper): social, technical, administrative, political, legal, and economic. The STAPLE forces shape the policy environment and are the key to reduction of community vulnerability. They vary with time, place, and circumstances (fig. 2). The hazard environment produces or generates the physical effects (hazards) which can adversely impact the community and its built environment. The built environment (i.e., buildings and lifeline systems) is at risk (i.e., faces potential loss from these hazards), depending on location, value, exposure, and vulnerability. The community decisionmakers determine the mix of risk management policies and practices that are needed to protect the people and the built environment.

THE PROBLEM

Many experts believe that the world's current technology base (i.e., information, knowledge, experience, and know how) is adequate to reduce any community's vulnerability to natural hazards (ref. 2). However, even though adequate technologies are available, they are not being transferred to end users and implemented at a rapid enough rate in both developed and developing countries to change the policy environment and reduce the risk. Too few communities have adopted policies that: 1) stop increasing the risk for new development, 2) start decreasing the risk for existing development, and 3) continue improving preparedness plans for the inevitable damaging event.

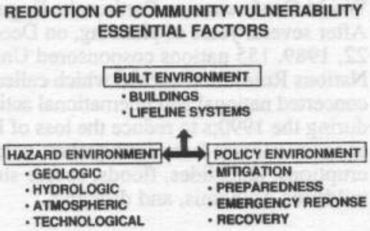

Figure 1.--Schematic illustration of the hazard-, built-, and policy environments which control community vulnerability to natural hazards.

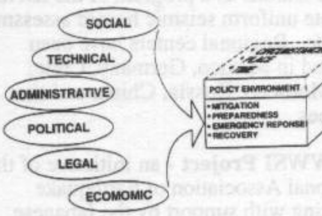

Figure 2.--The forces shaping the community policy environment that must be changed by technology transfer.

Three problems continue to hinder transfer of technology for natural hazard reduction throughout the world (ref. 3). They are: 1) resistance to change; 2) coordination and communication, especially at disciplinary interfaces, between researchers, practitioners, and decisionmakers; and 3) failure of end users to take "ownership" of new technologies (fig. 3).

Past experience (refs. 3-5) has shown that:

1. The status quo for natural disaster reduction will be maintained until external forces (e.g., those associated with political decisions or a natural disaster) compel changes in the hazard-, built-, and policy environments that will make the community's people, buildings, and lifelines less vulnerable to natural hazards.

2. Coordination and communication, especially at disciplinary interfaces between researchers, practitioners, and decisionmakers are not likely to change much until external forces compel them to work together at the margins of their disciplines to change the STAPLE forces.

3. Inability or reluctance of practitioners to take ownership of new technologies is often a result of lack of understanding of the technology, the inability to change the STAPLE forces, or not being part of the process(ref. 2).

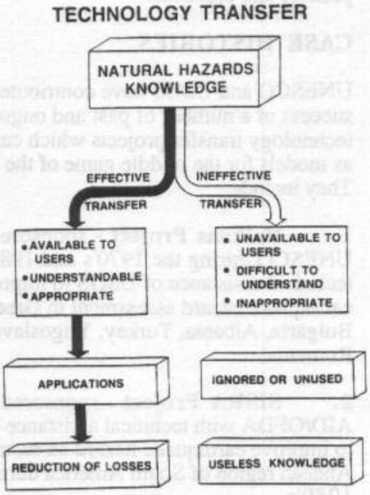

Figure 3.--Schematic illustration of the process required to transfer "ownership" of technology from researchers to practitioners.

THE SOLUTION

To be successful, the technology transfer program should seek incremental changes in the STAPLE forces. An accelerated worldwide technology transfer program should institutionalize a long-term process that will enable researchers, practitioners, and decisionmakers in a community solve work through the problems of apathy, communication, and understanding, thereby transferring the "ownership" of available technologies (i.e., information, knowledge, experience, and know how developed within and outside their country). The researcher is seeking answers to the questions: where, how big, or how bad and why; the practitioner to the questions: when, how big, how bad, and where; the decisionmaker to the questions: what should I do to save lives, reduce damage and economic loss that is feasible technically, socially, and economically. Once answered to everyone's satisfaction and the new technologies are owned; they can then be adapted for use in local risk management policies and practices.

CASE HISTORIES

UNESCO and USGS have contributed to the success of a number of past and ongoing technology transfer projects which can be used as models for the middle game of the IDNDR. They include:

1. **Balkans Project** - sponsored by UNESCO during the 1970's and 1980's with technical assistance of USGS to improve earthquake hazard assessment in Greece, Bulgaria, Albania, Turkey, Yugoslavia, and Romania.

2. **SISRA Project** - sponsored by AID/OFDA with technical assistance of USGS to improve earthquake hazard assessment in the Andean region of South America during the late 1980's.

3. **SEISMED Project** - sponsored by Italian government, UNDP, and UNDRO (now DHA) with technical assistance of USGS and others to foster earthquake risk reduction in the countries adjacent to the Mediterranean Sea during the late 1980's and early 1990's. Participating countries included: Spain, France, Monaco, Malta, Albania, Italy, Macedonia (former Yugoslavia), Turkey, Israel, Egypt, Syria, Greece, Cyprus, Libya, Morocco, Tunisia, and Algeria.

4. **WWERM Program** - sponsored by AID/OFDA with technical assistance of USGS to develop seismic zonation maps and risk assessments in major cities of Peru, Chile, Morocco, Indonesia, and the Philippines with eventual expansion worldwide during the late 1980's and 1990's.

5. **RELEMR Project** - sponsored by US Department of State with technical assistance of USGS and support of UNESCO to reduce earthquake losses in the Eastern Mediterranean Region (i.e., Turkey, Lebanon, Cyprus, Syria, Jordan, West Bank, Israel, Egypt, Saudi Arabia, and Yemen) during the period 1993-2000.

6. **GSHAP Project** - proposed by the International Lithosphere Program with sponsorship by the International Council of Scientific Unions as a program of the IDNDR to promote uniform seismic hazard assessment worldwide. Regional centers have been established in Mexico, Germany, Chile, Kenya, Morocco, Russia, China, and the Philippines.

7. **WWSI Project** - an initiative of the International Association of Earthquake Engineering with support by the Japanese government and technical assistance by the United States to facilitate the development and implementation of cooperative seismic risk reduction projects worldwide during the 1990's.

8. **PAMERAR Program** - the "Programme for Assessment and Mitigation of Earthquake Risk in the Arab Region" is an initiative sponsored by the Arab fund for Economic and Social Development and the Islamic Development Bank, with technical assistance from UNESCO, during the 1980's and 1990's.

9. **CERESIS** - headquartered in Lima, the Centro Regional de Sismologia para America del Sur, was created in 1966 by agreement between the Government of Peru and UNESCO to provide international and intergovernmental coordination. Eleven nations (Argentina, Bolivia, Brazil, Ecuador, Spain, Chile, Colombia, Peru, Trinidad-Tobago, Uruguay, and Venezuela.

10. **CENAPRED** - a national disaster prevention center established in 1990 in Mexico City through a cooperative program of the governments of Japan and Mexico. Technical assistance has been provided to: Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama.

11. **IFSZ** (International Forum on Seismic Zonation) - a project of UNESCO and USGS initiated in 1990 to identify the safest part of a geographic area for earthquake resistant development.

SUMMARY

The middle game of the IDNDR provides an unprecedented opportunity to improve and accelerate technology transfer for natural disaster reduction during the 1990's. An opportunity like the IDNDR is to accelerate and improve worldwide technology transfer for natural disaster reduction may never occur again.

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TOWARD IMPROVED TECHNOLOGY TRANSFER

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KEYWORDS: technology transfer, natural hazards, risk management,

ABSTRACT

This paper presents a model and describes two new initiatives for improving technology transfer. The model and the initiatives call for the following paradigm shifts:

1. Be proactive instead of reactive.
2. Improve leadership skills first, then management skills.
3. Organize and execute around a few critical activities that matter the most instead of the many that matter the least.
4. Think win-win, instead of "my way" or "your way."
5. Listen first, speak second.
6. Make 1+1=1,000 instead of 2.
7. Renew resources daily instead of intermittently.

INTRODUCTION

Countries throughout the world are seeking solutions to urgent local and national problems that differ only in their nature, social priority, and end points in time and space. These problems include:

1. Sustainability of economic development,
2. prevention of adverse environmental impact,
3. preservation of fragile ecological systems,
4. conservation of renewable and non-renewable energy resources, and
5. ensuring the safety of the populace at risk from natural and technological hazards.

It is well known that the solutions to these problems require innovative technology transfer. Innovation is needed because a paradigm shift must take place in either the researcher or the end-user, or both before ownership of information, knowledge, experience, and know-how and responsibility for its use can be transferred from researchers to end-users.

A model for improving technology transfer must include seven types of paradigm shifts (i.e., sets of specific changes or actions) that provide a new way of viewing or thinking about the problem. They are:

1. <u>Be proactive instead of reactive</u>.

Technology (e.g., information, knowledge, experience, and know-how) does not transfer itself; therefore, a deliberate, action-oriented and people-dependent process must be created by either the researchers or the end users or both to enlarge every one's circles of influence. This calls for a shift from the paradigm of reactive thinking, which always becomes a self-fulfilling prophesy, to proactive thinking.

2. <u>Improve leadership skills first, management skills second.</u>

Leadership comes first. Successful technology transfer requires leadership so that the people involved know not only where they are going but also why and when because they have the same vision, purpose, and direction. Leaders facilitate a paradigm shift from analytical, logical, and verbal skills to intuitive, creative, and visual skills.

3. Organize and execute around a few critical activities that matter the most instead of the many that matter the least.

   Leadership, commitment, and resources are the critical elements for transferring technology. After vision, purpose, and direction are set, managers focus on how it will be done by forming strategic coalitions, merging agendas, devising and implementing strategic plans, and forging strong interpersonal relationships. This calls for the difficult, but essential paradigm shift from fragmented individual efforts to integrated collaborative efforts.

4. Think win-win instead of "my way" or "your way."

   Technology transfer requires effective people-to-people interactions not only to implement the process but also to ensure that the proposed solutions are beneficial to everyone. This calls for a paradigm shift from an emphasis on "my way" or "your way" to "a better way."

5. Improve credibility by listening first, speaking second.

   Technology transfer from researchers to practitioners or policymakers initially requires as much or more listening as speaking. This will ensure credibility because experiences and new ideas will be placed in the context of the other person's needs, concerns, and paradigms. Listening is a major paradigm shift because people typically talk first and listen second.

6. Make 1+1=1,000 instead of 2.

   Technology transfer will succeed in a big way (e.g., 1+1=1,000) when strategic coalitions and merged agendas result in a higher level of trust, communication, and cooperation. These attributes will significantly leverage the available resources and the potential benefit of both the researcher's and end-user's circles of influence. This calls for a paradigm shift from independence to interdependence.

7. Renew resources daily, instead of intermittently.

   Although technology transfer is a long-term process, the rate of progress depends on how frequently and how effectively researchers and end-users renew physical, emotional, mental, and spiritual assets. Daily renewal provides more unexpected opportunities to learn and contribute to the dynamic process than intermittent renewal. This calls for a paradigm shift from the typical mind set of impossibility (e.g., "it cannot be done") and scarcity (e.g., "we cannot afford it") to one of possibility and sufficiency.

NEW INITIATIVES TO IMPROVE TECHNOLOGY TRANSFER

Two new initiatives, described below, are underway and will test the above model for technology transfer. The first initiative relates to the goal in the United States of community sustainability and resiliency to natural hazards; the second to the goal in the Eastern Mediterranean Region (EMR) of earthquake safety.

THE UNITED STATES AT RISK FROM NATURAL HAZARDS

Every State and Territory of the United States is at risk from one or more natural hazards which often strike communities with little or no warning. To cope with the great sudden loss potential represented individually and collectively by earthquakes, floods, severe storms, landslides, volcanic eruptions, wildfires, droughts, and tsunamis, the United States adopted a national goal in 1994 to take steps to reduce the risk. The goal has four components:

-- Safety Of The Populace,
-- Hazard Resilience of every community,
-- Sustainability Of Economic Development, and
-- Protection Of Fragile Ecosystems And The Environment.

To reach the goal, Federal, State, and local government; universities, professional and volunteer organizations; and the private sector are forming new or expanded coalitions to achieve specific risk management objectives (Figure 1). They include activities performed before, during, and after natural hazards strike, such as:

- Monitoring networks consisting of more than 25,000 land, water, and satellite based sensors to locate and characterize geologic and hydrologic hazards in time and space and to warn the public.
- maps, data bases, and geographic information systems;
- Basic research to determine "where," "how big," "how often," and "how bad;"
- Risk assessment (i.e., hazard, exposure, and vulnerability assessments) on national, international, regional, and local scales;
- Transfer of technology to end users responsible for reducing risk (i.e., mitigation, preparedness, emergency response, and recovery); and
- Post disaster investigations.

ELEMENTS OF RISK

Figure 1.--Elements involved in risk assessment and risk management.

The Nation's existing inventory which needs to be made resilient to natural hazards includes:

- Tens of millions of single and multiple family dwellings, including manufactured housing.
- More than 5 million miles of roads and highways, railroads, and transit systems.
- More than 5 million miles of underground pipelines associated with oil, gas, water, and electrical utilities.
- Hundreds of thousands of Federal, State, and private sector buildings.
- Hundreds of thousands of schools, colleges, and universities.
- Hundreds of thousands of factories and manufacturing facilities.
- Hundreds of thousands of small businesses and shopping centers.
- Approximately 575,000 bridges.
- Tens of thousands of civic centers and places of public assembly.
- Tens of thousands of hospitals and health care facilities.
- Tens of thousands of monuments, historic buildings, and museums.
- Thousands of ports and harbors.
- Thousands of conventional power plants.
- Thousands of military bases.
- Thousands of airports.
- Hundreds of dams.
- Hundreds of national forests and parks.
- Capitols of the 50 States and Territories.
- White House and Capitol.

At present, the Nation is winning the battle concerning loss of life, but it is losing the economic battle with natural hazards. Direct losses to buildings and infrastructure have reached $1 billion each week--$52 billion each year.

THE EMR AT RISK FROM EARTHQUAKES

The term, EMR, refers to those countries that are affected by earthquakes caused by tectonic movements along the western margin of the Arabian Plate. They are: Turkey, Cyprus, Lebanon, Syria, Jordan, Israel, Egypt, West Bank, Saudi Arabia, and Yemen. The EMR's seismicity is related to the tectonic forces that opened the Gulf of Aden and the Red Sea, that continue to transport the Arabian Plate northward at the rate of about 0.5 cm/year, and that formed the mountains in Turkey and Iran north of the plate boundary.

Damaging earthquake, tsunamis, and landslides have occurred repeatedly in the EMR throughout history and the geologic record shows clear evidence of seismotectonic deformation over millions of years. The Dead Sea transform, a 1,000 km-long left-lateral strike slip fault system, marks the western boundary of the Arabian plate; whereas, the East and North Anatolian fault zones, the latter a 1,200 km-long, right-lateral strike slip fault zone in Turkey, mark the northern boundary.

In 1993, the EMR countries in cooperation with USGS and UNESCO, adopted a comprehensive seven-point program to reduce earthquake losses. The program encompasses unilateral, bilateral, and multilateral activities such as:

1. Seismotectonic framework studies to improve understanding of the cause and nature of the seismicity.
2. Monitoring.
3. Assessment of earthquake hazards.
4. Assessment of risk.
5. Risk management.
6. Technology transfer.
7. Public awareness.

These programmatic activities are expected to increase the capacity of researchers, practitioners, and policy and decisionmakers to address four basic questions:

1. Which urban areas in the EMR are likely to be adversely impacted in the in the next 10, 20, and 50 years?
2. What are the expected losses during these exposure times for a range of realistic scenarios?
3. What are the most effective mix of risk management policies and strategies (i.e., mitigation, preparedness, emergency response, and recovery) that will control these losses and ensure sustainable development?
4. What social, technical, administrative, political, legal, and economic actions are needed to adopt and implement them?

CONCLUSIONS

These two initiatives should improve technology transfer from researchers to policymakers and practitioners in the United States and the EMR. They will provide a "laboratory" to test and refine the dynamic model for technology transfer.

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TIEMEC '95

Warning Systems for Emergency Management

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Technical University of Delft

COMMUNITY WARNING FOR TOXIC RELEASES FROM INDUSTRIAL SITES

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KEYWORDS: warning system, sirens, computer design

ABSTRACT

Many industrial facilities such as refineries, chemical plants and paper mills handle toxic substances for their operations. In order to alert nearby communities surrounding these facilities in the event of an emergency, an effective method must be used. Depending on the wind conditions and the nature of the toxic release incident, the response time must be kept very short (a matter of a few seconds). It has been determined that the most effective alerting method is to use fixed high power directional speakers within the fenceline of these facilities. The US Environmental Protection Agency (EPA), Occupational Safety and Health Administration (OSHA) and Federal Emergency Management Agency (FEMA) require these facilities to provide a reliable method to safeguard these communities.

This paper describes a system implemented for a community near Houston, Texas. It will describe the system's design and computer modeling to ensure proper acoustic coverage for the effected community. System hardware and software will also be discussed in the paper. Continuous status monitoring for the installed equipment and the communication system design will also be addressed.

In summary, this paper will highlight important aspects used to alert communities against technological disasters associated with the release of toxic fumes.

INTRODUCTION

A community warning system is for the purpose of alerting the residents in the event of a chemical accident/emergency that may result in harmful concentrations within the community. As a result of the severe time constraints involved with an accident, a warning must be issued immediately and must be capable of both indoor and outdoor alerting and notification. The warning siren alert signal is intended as an initial attention getting signal instructing the population to take necessary protective actions. In most instances, the siren signal instructs the population to get indoors, close all window, turn off any air conditioning systems to avoid drawing the chemical indoors, and turn on their local Emergency Broadcast System (EBS) television or radio station for further information. The residents living within areas nearby to the industrial plant must be instructed on how to respond to a siren signal through a public education program.

SYSTEM DESIGN CRITERIA

The Nuclear Regulatory Commission (NRC) and the Federal Emergency Management Agency (FEMA) have established acceptable outdoor siren signal criteria for public notification in the vicinity of nuclear power plants in their document NUREG-0654, Appendix 3 -- "Means for Providing Prompt Alerting and Notification of Response Organizations and the Population." "As an acceptable criteria at most locations, 10dB above average daytime ambient background should be a target level for the design of an adequate siren system." The 10dB dissonant differential refers to the ambient in the octave band surrounding the siren tone and is a conservative use of the 9dB differential which is discussed in FEMA document CPG-1-17. Research has shown that a person is capable of being alerted by such a differential above the background ambient in the case of a predominantly narrow band siren tone. The achievement of a positive differential of 10dB has been a basic objective of most siren system designs for outdoor alerting.

Available data relating to investigations into the effect of waking people from sleep indicate that for the time of deep sleep, an indoor warning signal of 60dB was sufficient to awaken approximately 60 percent of the test subjects. This means that the outdoor siren warning signal must be at least 75dB if one can assume about a 15dB transmission loss for building wall, given the type of housing construction (wood and brick) and wall insulation levels expected in the south. This report also indicated that a decrease in loudness of 5dB resulted in a waking loss of about 7 percent. It was also determined that a time duration of 60 seconds was sufficient for emitting the signal for waking purposes.

Using this information, it was determined that an outdoor siren signal level of 75 dBC is an adequate design for indoor notification.

With regard to *nighttime indoor* notification for waking people during sleep, several factors tend to improve system's indoor warning capability. During the nighttime hours, ambient sound levels due to traffic and other outdoor activity as well as indoor noise levels (especially during sleeping hours) are substantially lower, which should help to make the warning signal more noticeable indoors.

Electronic, high power directional sirens for fenceline alerting have been chosen due to their capability of operating off a battery source which can be integrated with a solar power energy system.

ACOUSTIC COMPUTER ANALYSIS

Siren sound levels for siren locations are calculated by a computer model developed by ATI. This model is based on outdoor sound propagation theory used in conjunction with empirical factors to closely correlate the results with field test data. ATI has made extensive acoustic measurements at siren systems across the country in order to evaluate and perfect this model.

For siren system analysis, the primary inputs to the computer model are site specific topography (building and land elevations), ground cover and meteorological conditions. Topography and ground cover in the vicinity around each siren. Summer average temperature, humidity, wind speed and direction are computed from data gathered at local site weather monitoring station and the National Climatic Data Center. This information is used to calculate the sound attenuation due to the sources described in the following sections.

The various factors (see Figure 1) considered in the sound propagation analysis by the computer model are summarized as follows:

a. Hemispherical Wave Divergence
b. Atmospheric Absorption
c. Wind Shadows
d. Ground Cover Absorption
e. Barrier Attenuation Effects

The extensive program of field testing has proven the ATI siren computer model to be an accurate and reliable estimator of siren acoustic coverage for all siren types and models to which it has been applied, as well as a wide variety of topographic and ground surface conditions.

FEMA guidelines suggest that average summer daytime weather conditions be used to calculate siren sound contours.

SYSTEM CONFIGURATION AND DESIGN

The portion of the community targeted for fenceline siren alerting is a significant area within the Community Emergency Planning Zone (EPZ). The industrial plants within the community have been grouped into 3 major zones: the East Zone, the North Zone and the West Zone. The optimum system design consists of fifteen fenceline siren sites for the three zones. The fifteen sirens were determined to be sufficient to acoustically cover the fenceline areas within the EPZ. These locations require sirens with directional horns to optimize the alert coverage within the community.

Each fenceline siren is located on one of the industrial plant's property. In most cases, this means that access to the site for installation and future maintenance of the siren will be through the designated plant. The extent of the sound coverage from the fenceline sirens is shown on Figure 2.

Additional Community Siren Coverage: If blanket coverage of the entire community Emergency Planning Zone (EPZ) is required at a future time, additional community sirens can be installed. ATI designated tentative locations for additional community sirens.

Maximum Noise Level Exposure Analysis: In order to insure that there is no public risk to excessive noise exposure, a computer analysis was performed to determine the maximum noise exposure to any residence in the immediate proximity of the siren. This computer analysis was based on the following general assumptions:

1. The siren may be modeled as a point source;
2. The receiver lies in the far field;
3. The atmosphere is still, isothermal, and homogeneous; and,
4. The ground is a perfect reflector.

The predicted sound pressure level was determined by considering the effects of ground reflection, hemispherical divergence, atmospheric absorption, and directivity pattern on the propagation of sound between source and receiver.

From this analysis, a maximum sound pressure level of 117 dBC at a distance of 100 feet from the siren pole (in the direction that the siren horns are pointing) was determined. This value is less than 123 dBC, the level considered to cause discomfort to an individual. These results strongly indicate that the sirens are safely located with regard to noise exposure criteria.

Figure 3 illustrates the system configuration. Each zone has an independent controller to control its' zone sirens. Also there is a central controller located at the city police station. This central controller can activate individual sirens, a group of sirens, or the entire system. The siren system uses a radio frequency (RF) communication infrastructure for status monitoring and activation of the sirens.

Radio Frequency Propagation Study: In order to determine actual radio signal strength and to identify potential system problems for the community siren system, a radio frequency propagation study was performed during the system design phase. Radio signal propagation losses were compared to expected losses to determine attenuation effects of man-made structures as well as vegetation. Finally, the radio system design constraints were confirmed. The survey confirmed the feasibility of using the licensed frequency, 154.980 MHz, with 25 watts effective radiated power (ERP) with 15 watts maximum output power which is given by the license. Also confirmed were the type of antenna and configuration that were needed to achieve reliable radio communications.

The fenceline siren system was installed and is maintained by the local industrial plants. The system design includes a user-friendly software package running on the personal computers at each control station. The siren system software package provides status monitoring and maintenance information for operators and after siren activations, verification information on the success or failure of the sounding.

CONCLUSIONS

The results of ATI's site survey and radio propagation survey provided enough data to enable a highly reliable design of an Industrial fenceline community warning system. The system of fifteen sirens described in this paper sufficiently covers the area immediately around the various industrial plants.

The following main conclusions can be drawn from this paper:

1. Adequate 75 dBC for indoor and 65dBC for outdoor acoustic coverage is provided by 15 stationary high power electronic sirens for the fenceline community near the industrial sites.
2. Placement of sirens did not pose any environmental noise impact to humans or animals in the near field of the sirens.
3. The central and zone controller stations transmit and receive radio signals reliably with the siren's controller utilizing the 154.980 MHz radio frequency.
4. The warning system and its radio control system will provide adequate means for prompt alerting of the nearby public in case of an emergency at the industrial facilities.

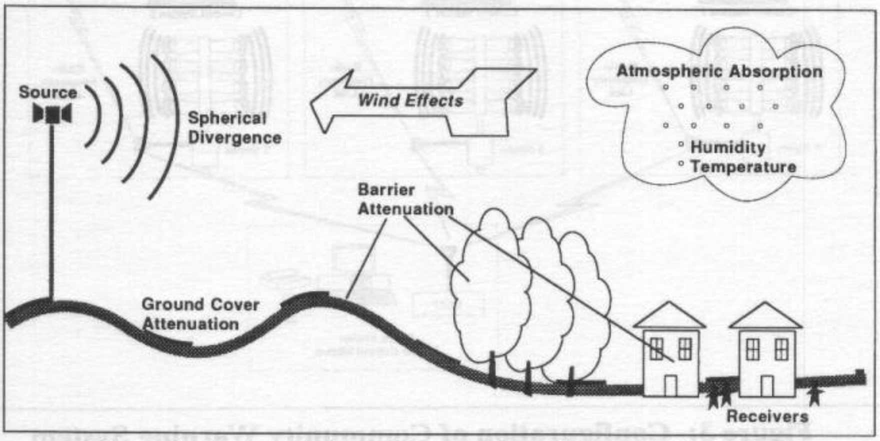

Figure 1: Factors in Sound Propagation Computer Modeling

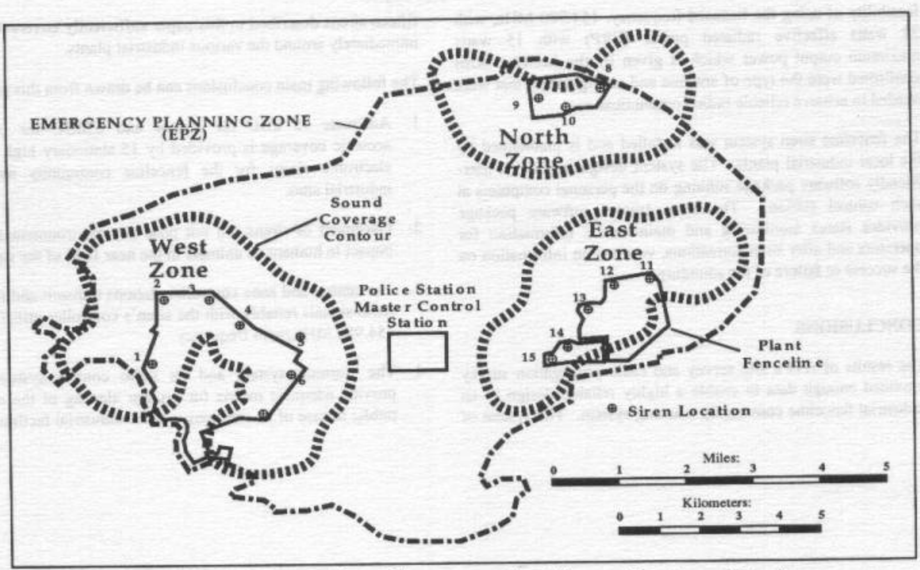

Figure 2: Fenceline Community Siren System Design

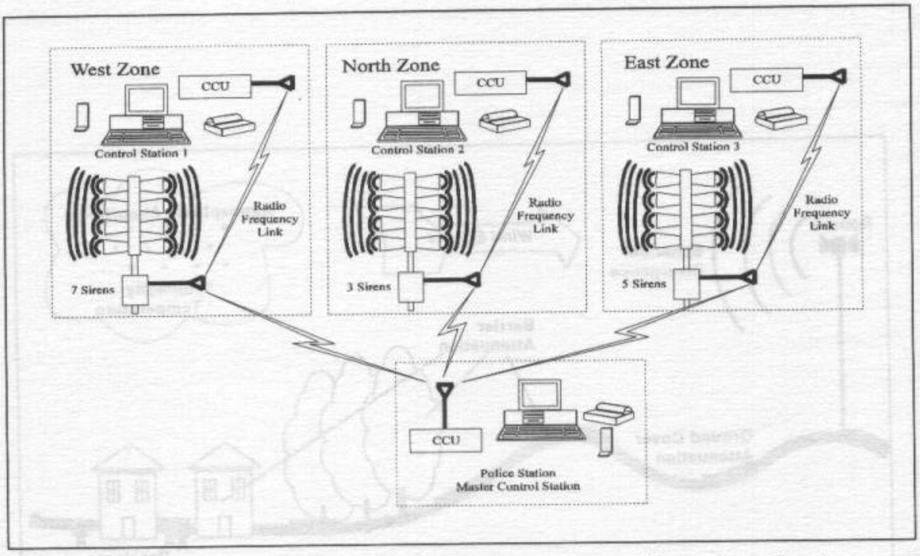

Figure 3: Configuration of Community Warning System

DEVELOPMENT OF PRINCIPLES OF EFFECTIVENESS EVALUATION OF FIRE–ALARM SIGNALING SYSTEMS

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KEYWORDS

fire-alarm signaling systems, effectiveness evaluation

ABSTRACT

Principles are described for evaluating the effectiveness of an automated fire–alarm signaling system, in contrast to visual detection of fires.

The main aim that is pursued when equipping any object with a fire alarm system consists of reducing detection time and, accordingly, minimizing the period of uncontrolled fire development, before fire–fighting agents of an active fire defense are introduced. Doing so, it becomes possible to cut down material damage from the fire and, in the majority of cases, to avoid disastrous consequences.

The effectiveness of a fire–alarm signaling system (FASS) is defined by its ability to contribute to achieving gain with the least expenditure in all allowable exposure ranges.

It is obvious that early fire detection itself, with FASS functioning irreproachably, is not by itself a guarantee of quick extinguishing of a fire. The arriving signal must be received, processed, and sent to the fire command, whose watch must arrive at the object, detect the fire, and put it out. In particular cases, variations of this scheme are possible without changing its essence; for example, automatic signal transmission to the fire command, or extinguishing of the fire by an object's own personnel.

From what is said above, it follows that, in the conception being worked out of quantitative estimates of FASS effectiveness, one should take into consideration not only technical parameters of the system's elements that guarantee the fulfillment of its main task, but also the characteristics of defended objects having an influence on fire development and the level of fire–fighting measures.

Among the system's parameters subject to exploration are the following: the fire–alarm sensitivity; the time of signal processing with a receiving and monitoring device; and the availability of direct transmission of a signal to fire command.

Since the fire start time depends on the exactness of pointing out the fire location, the number of addresses in the system needs to be included, too, as one of the indicators producing an effect on its effectiveness. On the other hand, the criterion being worked out should take into account the diminution of FASS effectiveness with the growth of the frequency of false signals produced by the system that do not accord with the state of the checked object.

The criterion sought for is to provide an opportunity to bring together various system characteristics and a defended object (not connected with each other, and having different quantitative dimensions) into a single integral indicator characterizing the object's protection by means of fire signaling.

As at any object, defended lodgings are different from the point of view of their fire security. So, when using the same hardware components of automatic detection, the expected lowering of fire loss appears to be different. Therefore, the quantitative indices of FASS effectiveness should be determined separately for every defended apartment, and after that be generalized while passing on to a real object with an arbitrary number of defended apartments.

Bringing together all the examined parameters into economic indices gives us a chance to make proper generalizations.

In the majority of cases one may choose as a criterion of FASS effectiveness the relationship between the expected damage decrease from a probable fire and the object's required equipment expenditure for fire–alarm signaling (all of the economic indices used in the subsequent calculations are given by the year of operation):

$$W = (m_b - m_c)/M_c \qquad (1)$$

where m_b is the value of expected fire damage in the case of visual detection (we (assume no additional expenses to reduce the time of visual detection are made); m_c is the expected damage when using fire–alarm signaling; and M_c is the expenditure connected with equipping and operating FASS for an object.

In general, in the numerator of the relationship (1), not only direct, but also indirect, losses have to be considered. However, considering early fire detection and liquidation to lead to minimizing both direct and, all the more, indirect damage, the indirect losses may be taken into account only in quantity m_b.

However, the possibility of applying the offered criterion is limited by the fact that for a number of defense objects the fire hazard is associated not only with material losses. Thus, at objects of mass peoples' residence, prolonged uncontrolled fire development (for instance, in zones of escape routes) may result in terrible consequences connected with human victims. Besides that, in a number of cases, late fire detection in one lodging may result in loss of the whole defended object. In fact, the question is one of a substantial rise in indirect damage from a fire with respect to direct damage.

When realizing fire–protection measures at an object of this sort, the question of the material values of directly defended apartments becomes a secondary one. In such cases, one can usually determine an allowable time limit of detection, T_{pr}, which is specified proceeding from the concrete peculiarities of an object of defense. Exceeding the time limit is fraught with grave or extremely grave consequences.

In conformity with such an object of protection, it is possible to perfect criterion (1), keeping in mind the following prerequisites. As long as the prescribed goal (the limitation of detection time) may be achieved at various material expenses, the economic effect is defined as the expenditure difference that is necessary for promoting discovery during a time period not exceeding T_{pr}, when using fire–alarm signaling versus visual detection:

$$M_c = M_o + M_{pm} + M_{to} + M_{oa} \qquad (2)$$

where M_o is the cost of the fire–alarm signaling apparatus and components; M_{pm} is the cost of design work and assembly; M_{to} is the cost of maintenance and repair; and M_{oa} is the material damage done to the consumer in case of apparatus failure.

For the practical application of the suggested quantitative effectiveness criterion of fire–alarm signaling, it is necessary to offer calculation principles, being not evident, of some parameters forming parts of expressions (1) and (2). Possible definitions of these parameters, using available data, are presented below.

First, let us define the expected damage reduction owed to using fire–alarm signaling: $(m_b - m_c)$. For simplicity, a conditional lodging with a common nature of combustible load and a uniform distribution of material values over the area is investigated (apartment index i is omitted). The time reading begins from the origin of the site for ignition.

The maximal time to the start of putting out the fire, T_{nt}, is:

$$T_{nt} = T_o + T_{pp} + T_{br} + T_{po} \qquad (3)$$

where T_o is the maximal time of fire detection at the object (from the start of burning till the fire detector's operation); T_{pp} is the time of decision-making by the receiving and monitoring desk, and signal transmission to the duty command; T_{br} is the time of moving to the object, and combat deployment of the fire protection unit; and T_{po} is the time of searching the site for the hotbed.

The difference in values, T_{nt}, obtained from expression (3) when automatic versus visual discovery happens, may reach some dozens of minutes.

To make calculations it is necessary to know the principle of assigning the quantities T_{ntc} and T_{ntv}, where T_{ntv} is the time of putting fire–fighting agents into operation upon visual discovery, and T_{ntc} is the time of putting them into operation upon automatic discovery. The value of T_{ntv} is computed according to formula (3) after substituting T_o for T_{ov}, the maximal time of visual detection. The last quantity may be obtained either from available statistical data, or on the basis of analysis of the protected lodging or an adjacent one. The search time of the site for ignition, T_{po}, is determined by the number of apartments protected within one plume, and also by the average time to access and survey one apartment, specified for concrete groups of apartments. For simplicity, T_{po} may be defined with the expression:

$$T_{po} = \alpha(N - 1) + \beta \qquad (4a)$$

where N is the number of detectors in the plume; α is the average time of one apartment's survey; and β is the time of access to the group of apartments defended within one plume.

For address systems (or in the case of plume defense of only one apartment):

$$T_{po} = \beta \qquad (4b)$$

So, from the parameters used in the value calculations, $(m_b - m_c)$, uncertainty concerning the assignment of quantity T_o, the time of fire discovery when using FASS at the object, does not vanish.

In view of the diversity of possible alternatives of fire development, it seems to us to be unrealistic to give an accurate forecast of the nature of change in factors accompanying burning. One of the possible ways to formalize the task consists of hypothetically substituting for the real hotbed site a standard site whose composition is similar to the combustible load of the defended apartment. Supposing that the location of ignition is the furthest point in an apartment from the nearest fire detector, one may determine the maximal time of reaching the operation threshold of the fire detector with the parameter being inspected, and accordingly, the maximal time of discovery. To eliminate the subjectivity of such an approach when choosing a standard, it is appropriate to use sites for ignition similar to those determined by the European Standard, EN–54 (part 9), for testing fire detectors.

To obtain the values of T_o, it is necessary to know the operational thresholds of the fire detectors chosen for setting up in the apartment. For smoke detectors, that is the threshold smoke concentration, C_{por}, at which fire–detector operation occurs. For heat detectors, it is the threshold temperature, T_{por}, or the rate of its rise. Assuming that the probable site for ignition may be situated at at an arbitrary point of the apartment, when determining the time of discovery we must set values of R_{max}, from the arbitrary point of the object defended to the nearest fire detector.

Then, solution of the equations:

$$C_{TFi}(R_{max},h,t) = C_{por} \quad (5)$$

and

$$\grave{a}_{TFj}(R_{max},h,t) = T_{por} \quad (6)$$

relative to t (where h is the height of the apartment) yields quantity T_o, the maximal discovery time of the checked site for fire TFi, that may be applied in expression (3). It should be noted once more that T_o is the time of discovery of the least favorably located of the checked ignition sites. The real time may differ from T_o in either direction.

The character of the time relations of temperature and smoke concentration in the apartment, (5) and (6), when the checked ignition sites are burning, may be specified either by computing, using a mathematical model of the initial fire stages, or on the basis of regression analysis of the experimental data, obtained in the process of experimenting on the ignition test sites.

In order to define the represented cost of apparatus failure introduced into formula (2), M_{oa}, it is necessary to elucidate the frequency and behaviour of the fault system. Since a legitimate signal is always present in the FASS plume at a background disturbance exerting an effect on the primary transducers or the data channels, the decision made by the system is of a probabilistic character.

The exhaustive list of feasible states of a non–address system is given in a table.

In order to evaluate operational effectiveness, it is necessary to determine both the principal possibility of realization of different states, A_{ik}, and the conditional probability, P_{ik}, of a desk's being in mode i at action k.

It is evident that failure omission and fire omission lead to various material losses.

Introducing the notion of cost, r_{ik}, of every examined consequence of the situation (the cost of right solutions, $r_{11} = r_{22} = r_{33} = 0$), and taking into account *a priori* probabilities of every signal appearance, P_k, for a typical concrete object, we obtain the expected average cost of unsatisfactory operation of the fire alarm signaling system.

Knowing the quantity, T_{pr}, it is possible to define the required level of expenditure to ensure such detection time without applying a fire alarm signaling system, at the expense of organizing a permanent watch or periodic rotations.

It is necessary to survey every apartment, i, not less frequently than time interval, T_{pr}. Having implemented this requirement, the following condition should be carried out:

$$H \times \delta(t_o) \leq \max(T_{pr}), \quad (7)$$

where H is the average number of apartments supervised by one man, and $\delta(t_o)$ is the average time of surveying one apartment.

The suggested conception defines a perspective direction for developing ideas of FASS effectiveness. The expediency of conducting appropriate investigations in the given direction is beyond any doubt. *A priori* estimation of the fire alarm signaling system allows us to optimize the solutions to problems of apparatus development, an object's equipment with the fire alarm signaling system, or its modernization.

It needs to be noted that the level of an object's fire protection is characterized by a number of indices, FASS effectiveness being only one of them.

It is no less important to secure constructive fire fighting protection, and to solve tasks appearing in the field of fire prevention. But, the possibility of independent effectiveness appraisal by means of the fire alarm signaling system only arises from the fact that, when FASS functions normally, a fire is discovered and liquidated at an early stage, while developing within the limits of one apartment, until the behavior of its development starts influencing the constructive defense. Therefore, the quantitative effectiveness index of fire alarm signaling systems is independently significant; and, at the same time, it may be applied to the complex estimate of the level of an object's fire fighting defense.

Global Emergency Observation, Warning & Relief Network

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ABSTRACT

The decade of the 1990's has been proclaimed by the United Nations to be the International Decade for Natural Disaster Reduction (IDNDR). During the first four years of the IDNDR, little progress has been made in mitigating the problem of providing prompt and effective warning and relief for natural disasters on a global scale. There exists a documented need for improved communications and information distribution to provide adequate warning in the face of impending disasters and facilitate the response after a disaster has occurred. The Global Emergency Observation Warning and Relief Network (GEOWARN) is proposed as a system that can potentially fill the existing gaps in the disaster management capabilities by providing a mechanism for the timely processing of information both before and after an event has occurred. The improved information management capabilities that would be provided by the GEOWARN system would complement the activities of existing international and national disaster management and meteorological agencies, as well as local government and private response organizations.

The GEOWARN system concept originated as a student design project at the 1993 International Space University (ISU) Summer Session. The student design team, composed of 38 students from 16 countries, formulated a proposed system design that would utilize existing remote sensing resources augmented by additional satellites and airborne sensor platforms linked together via a computer network. This network would be configured around five control centers called Multi-National Centers which would host an extensive Geographical Information System to perform the task of providing global disaster warning and relief support. To support the potential development of GEOWARN, the NASA Marshall Space Flight Center performed a study to assess concept feasibility. This study has resulted in several recommended modifications to the ISU system concept. It was concluded that a system design which optimizes the use of existing resources can result in significant improvements in disaster warning and management capabilities for most of the world. This paper presents the results of the feasibility study, including a general overview of the GEOWARN concept and the elements comprising the system.

INTRODUCTION

The impact of natural hazards on humanity is an ever-increasing problem. Natural disasters cause more that US $100B worth of damage and claim more than 150,000 lives annually. The increasing impact of disasters has drawn the attention of disaster relief officials, humanitarian organizations and governments worldwide. The United States Government, the United Nations, and other governments to begun to focus effort on mitigating the deleterious effects of natural hazards on the human population and supporting infrastructure. No technological breakthroughs are required to implement a global system capable of performing the functions required to provide sufficient information for prevention, preparedness, warning, and relief from natural disaster effects. The Global Emergency Observation Warning and Relief Network (GEOWARN) has been proposed as a system which would combine the elements of remote sensing, data processing, information distribution, and communications support on a global scale.

ORIGIN OF THE GEOWARN CONCEPT

The GEOWARN Concept was originally developed at the 1993 Summer Session of the International Space University (ISU) hosted in Huntsville, Alabama, USA. During the ten weeks of intensive interdisciplinary space studies, the international student body, comprising 100 graduate and post-graduate level students from 30 countries, engaged in the development of two student design projects. GEOWARN was one of the design projects and was supported by 38 students from 16 countries in America, Europe, Africa, and Asia.

The four primary functions of the GEOWARN system include data collection, data processing and management, information distribution, and communications support. Data will be collected via space-based, airborne, and ground-based remote sensing platforms. The data processing and data management elements the GEOWARN system will include geographical information systems, simulations of hazard phenomena and data bases. Data will be processed into usable products based on specific information requirements, then transmitted to the appropriate government and private disaster management agencies. The GEOWARN system will provide value-added information to disaster management officials to support preparedness, warning, and relief activities. The primary motivation for the GEOWARN project is a clear need to provide warning and relief support to those countries and regions of the world that currently do not enjoy these services. Furthermore, the United Nations (UN) has declared the decade of the 1990's to be the International Decade for Natural Disaster Reduction (IDNDR). The GEOWARN system would support the third main objective of the IDNDR: ready access to global, regional, national and local warning systems and broad dissemination of warnings.

The National Aeronautics and Space Administration (NASA) is supporting the activities of the IDNDR. NASA's unique remote sensing, data processing and communications assets provide information that could result in improved warning and relief capabilities. GEOWARN could utilize NASA assets to provide immediate benefits from NASA's Mission to Planet Earth program and the U.S. Information Superhighway initiative.

A PROMISING CONCEPT FOR GLOBAL WARNING AND RELIEF

There are many immediate and tangible benefits of the GEOWARN system. The most significant is that it would save lives and reduce human suffering throughout the world. It would also result in economic savings by reducing the extent of damage through preparations that could be made with adequate warnings or by more efficient disaster response activities. When compared to the total economic impacts of disasters, the cost of implementing GEOWARN is relatively small. GEOWARN would utilize existing technologies in an innovative and efficient manner to provide many benefits to regions of the world that normally would not derive the benefits of technology. GEOWARN would contribute toward a significant improvement to the disaster warning and relief capabilities for many parts of the world, including the United States.

Rather than invest scarce resources in the development of new infrastructure to support the development of a global warning and relief system, the GEOWARN system would be implemented incrementally, capitalizing on existing remote sensing platforms, data centers, and communications capabilities. The ISU study concluded that to fulfill the derived technical requirements, new space-based remote sensing platforms are required to compliment existing satellite observation systems. Aircraft-mounted remote sensing capabilities would also be exploited to allow quick response and eliminate the possibility that a remote sensing satellite may not be in the proper position to make the required observations. Relevant international, social and organizational issues were also considered.

Based upon an extensive characterization of natural hazards, and an evaluation their impacts on humanity, as shown in Figure 1, the ISU student design team developed a set of functional and technical requirements for a global warning and relief system. The vast majority of damage and death results from only eight disasters, all others cause, less than 5,000 deaths and cost less than US $5 billion annually. Droughts and infestations result in significant economic and human losses. In fact, more than one third of the world's food supply is lost to drought, infestation, and crop disease every year. The ISU team chose to omit the inconsiderate use of pesticides and major armed conflicts from further study because these events, were viewed as social problems, not natural hazards. The remaining six disasters fall into two classifications; rapid on-set disasters, and creeping (or long term) disasters. Rapid on-set disasters include floods, cyclonic storms, and earthquakes. Creeping disasters include drought, infestation, and crop disease. It was assumed that these six disasters would drive the technical requirements for the GEOWARN system, and that if the system satisfied the requirements for the these disasters then it would satisfy the requirements for virtually all other natural disasters. Remote sensing, communications and data management elements of the system were identified based on the derived requirements.

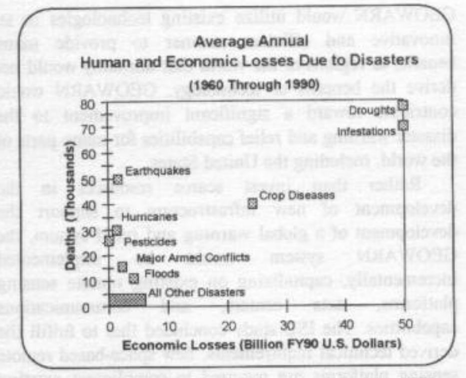


Figure 1. Disaster Priorities Identified by ISU

The ISU design project group developed an architecture for the GEOWARN concept which id depicted in Figure 2. The applicability of many current and proposed space-based assets, such as existing and planned geostationary weather satellites was examined. To obtain the temporal, spatial and spectral coverage required for full system implementation, the team proposed the development of six new satellites that would be placed in polar orbit equally spaced around the globe. The sensor suite onboard these satellites would be comprised of visible, infra-red, and passive microwave detectors. Data from these satellites would be downloaded to two ground stations located in Anchorage, Alaska and Trømso, Norway.

The space-based remote sensors would be augmented by a fleet of 30 aircraft dispatched from 20 different locations around the world to provide rapid response capability if an appropriate satellite platform is not in the proper position. These aircraft are would be outfitted with visible, infra-red, and synthetic aperture radar sensors. External information sources would include ground based sensors such as earthquake sensors and weather radars. Data processing and information distribution would be at five Multinational Centers (MNCs) located on the five major continents. Each MNC would be responsible for a specific region and maintain extensive data bases and geographical information systems. GEOWARN Headquarters would function as a management center and probably be located in Europe. Information would be shared between MNCs via existing telecommunications systems as well as the Internet. The GEOWARN system would use Internet for day-to-day communications but would also have the capability to use satellite links and portable communications systems if lines to a disaster area are not intact.

THE NASA MARSHALL SPACE FLIGHT CENTER GEOWARN FEASIBILITY STUDY

In an unfunded concept feasibility study, the Program Development Office of the Marshall Space Flight Center (MSFC) evaluated the merit of the ISU

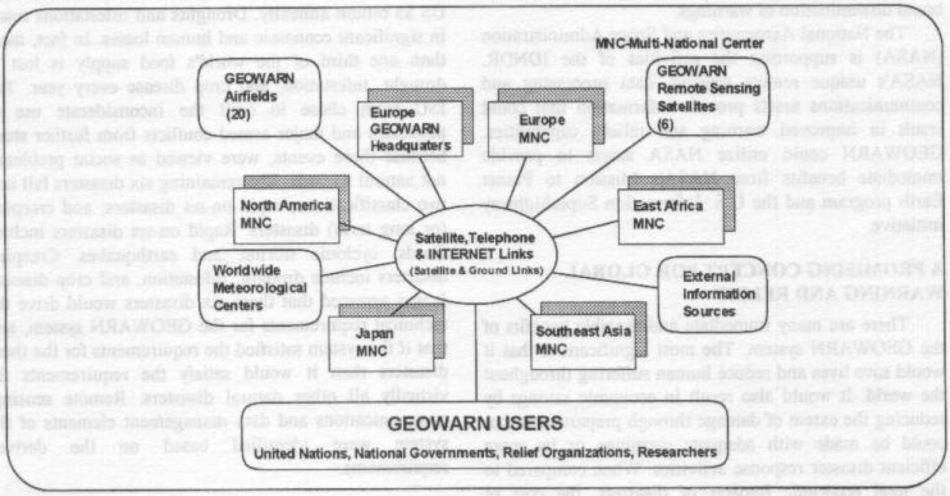


Figure 2. ISU Proposed GEOWARN Architecture

GEOWARN concept. The goals of the feasibility study included: 1) assessment of the technical, programmatic, and implementation aspects of GEOWARN; 2) identification of remote sensing, communication and data processing requirements; and 3) identification of space based, airborne, and ground based GEOWARN elements. The study results were documented in May, 1994.

Discussions on the GEOWARN concept were held with many organizations within the disaster management community. These organizations included the National Weather Service, United States Geologic Survey, Department of Defense, Department of Energy, American Red Cross, several United Nations organizations and other international agencies. There was a strong consensus among the organizations that a GEOWARN system is needed and would provide a valuable contribution in providing information and communication resources to the disaster management community. A significant conclusion of the evaluation is that there are absolutely no technical impediments to achieving the goals of the GEOWARN system. A plethora of potential system elements were identified during the course of the study that meet the operational requirements. These elements include a remote sensing satellites, ground receiving stations, data processing centers, satellite communications systems, detailed geographical information systems, and user interfaces designed specifically for emergency management officials.

As in the International Space University study, the MSFC study assumed that six primary natural disasters would drive the system requirements. These primary disasters and the parameters that must be known to provide warning or relief support are listed in Table 1. The three disaster types on the left of the table are "creeping" disasters and the three on the right are "rapid onset" disasters. An examination of these parameters shows that this set is applicable to many other types of disasters. This result validates the assumption that was made concerning the applicability of the requirements for the primary disaster types to many other types of disasters.

The Marshall study differed from the ISU study in several aspects of the remote sensing requirements. Rather than deploy six new remote sensing satellites, it was concluded that a significant disaster warning and relief capability could be achieved through the use of existing and planned remote sensing satellites if timely access to the measurements were possible. Many of these satellites have been proposed as part of NASA's and Mission to Planet Earth Initiative. While the primary objective of this initiative is to monitor the Earth's ecological system and study global climate change, many of the remote sensing elements could be directly applied to natural disaster monitoring. Additional satellites would however, provide increased surface coverage and reduced imaging turnaround time as they are incorporated into the system.

Table 1. Remote Sensing Parameters for Primary Disasters

Disaster	Parameter	Disaster	Parameter
Drought	Precipitation Distribution Precipitation Quantity Vegetation Distribution Vegetation Health Surface Winds Surface Temperatures Geographic Images	Earthquake	Crustal Motion Geographic Images
Infestation	Precipitation Distribution Precipitation Quantity Vegetation Distribution Vegetation Health Surface Winds Surface Temperatures Soil Moisture Geographic Images	Flood	Precipitation Distribution Precipitation Quantity Snow Distribution Snow Quantity Water Level Water Flow Rates Geographic Images
Crop Disease	Precipitation Distribution Precipitation Quantity Vegetation Distribution Vegetation Health Surface Winds Surface Temperatures Geographic Images	Hurricane	Location of Storm Precipitation Distribution Precipitation Quantity Wind Velocity Surface Temperatures Temperature Profiles Humidity Profiles Geographic Images

As shown in Figure 3, GEOWARN will use a broad communications and data management architecture. The commercial sector has played a major role in the development of global communications systems such as INTELSAT and INMARSAT. Future communication networks will provide a pathway to global communications using global networks such as IRIDIUM (Motorola), Odyssey (TRW), Goldstar(Loral/Qualcomm), and Project 21 (INMARSAT). All of these LEO systems can handle voice, fax, and low rate data. In addition, there have been efforts to develop wireless Local Area Networks (LANs) which may be of great benefit to GEOWARN in the future. The processing of remote sensing information into specific GEOWARN products could be performed by the satellite operators at the ground receiving stations or in distributed data processing centers such as NASA's EOS Distributed Active Archive Centers (DAACs'). There are also commercial companies, such as EOSAT, that processes raw satellite data.

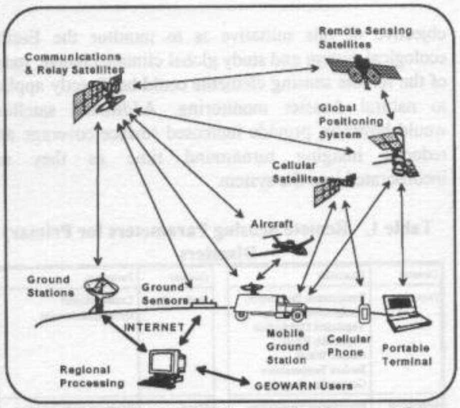


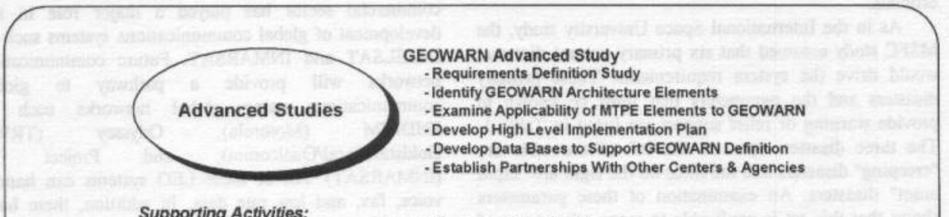
Figure 3. GEOWARN Communications and Data Management Architecture

Geographic information systems (GIS) provide a method to analyze data from several unique perspectives which can then be used to identify relationships between different types of information. The data is organized according to geographic locations and collected as layers in a large data base. These layers of data can include relatively fixed information such as surface elevations or time varying information such as weather conditions. The data layers can also include derived information such as flooding or air pollution models. Data in a GIS can be processed very quickly to provide updated maps, images or provide comparative data on conditions before and after a disaster for use the initial response and damage assessment.

The MSFC study did not attempt to define a detailed system architecture because there were numerous issues that require further study. However, it was concluded that decentralized international, national and regional management of GEOWARN elements might provide an efficient alternative to the Multi-National Centers proposed in the ISU study. The decentralized organization structure would allow individual countries to utilize GEOWARN elements within the framework of their established disaster management agencies and have more control in defining products best suited to their needs. This philosophy allows the GEOWARN architecture to vary for each country. The GEOWARN system would operate as an information resource rather than an operational or monitoring organization.

FUTURE STUDIES AND DEMONSTRATION PROJECTS

The Marshall Space Flight Center Study has identified many potential roles for NASA in the development of the GEOWARN system. These roles are summarized in the potential follow-on activities listed in Figure 4. Prior to specifying the details of a final system configuration, an in-depth technical requirements study is necessary to ensure that all critical parameters are



GEOWARN Advanced Study

- Requirements Definition Study
- Identify GEOWARN Architecture Elements
- Examine Applicability of MTPE Elements to GEOWARN
- Develop High Level Implementation Plan
- Develop Data Bases to Support GEOWARN Definition
- Establish Partnerships With Other Centers & Agencies

Joint Projects With Other Agencies

- Conduct Pilot Projects with Emergency Management Agencies
- Demonstrate Aerial Disaster Damage Assessment (CDDF)
- Demonstrate Transmission of Disaster Information
- Develop Applicable Geographical Information Systems
- Participate in U.N. Projects (IDNDR, IRRRIS & OLIVIA)
- Participate in IDNDR Information Management Projects (EPIX)

Concept Development

- Increase Global Precipitation Monitoring
- Enhance Partnerships With Industry
  - LEO Small Sats for Environmental Observations
  - GEO Com. Satellites w/ adv. Environmental Sensors

Figure 4. Recommended GEOWARN Follow-On Activities

addressed. In keeping with the incremental development scheme, advanced satellite systems could be incorporated into the GEOWARN system as they are launched, additionally, new satellites may be needed. Future advanced studies will also define the potential elements of the GEOWARN system, particularly the elements which could be provided by NASA. Efforts to involve international organizations in the studies are ongoing. The study identified a number of agencies throughout the United States and the world that are aggressively pursuing individual projects which could be integrated into the GEOWARN concept. These activities could provide the basis for future cooperative efforts. Development of the GEOWARN concept will require significant inter-agency and international cooperation.

CONCLUSION

The development of a global disaster warning system has been considered as one of the most promising peaceful applications of space technology for many years. It is evident that much of the technology that is used for scientific investigation of the Earth's environment and global communications can be applied directly to mitigate the impacts of natural disasters on humanity worldwide. There is also great potential for the reinvestment and dual use of technologies that have been developed for military purposes in disaster mitigation and response. The application of space based assets to disaster warning and relief activities is a very open ended problem. There are numerous examples that could be cited as proof of the potential benefits of a global disaster warning system. The GEOWARN system is a concept that would integrate current remote sensing, data management and communication technologies to provide disaster warnings and aid in disaster response on a global scale.

There are many potential roles NASA could undertake in the development of the GEOWARN system. NASA has many assets that could be used in the GEOWARN system for remote sensing, communications, and data management support. NASA could also participate in the integration of existing international capabilities and activities related to the GEOWARN system. One very significant role for NASA could be to make data from the Earth Observing System available to the GEOWARN system on a near real-time basis. This would provide an additional highly visible application of NASA's Mission to Planet Earth which would provide significant benefits to all of humanity.

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TIEMEC '95

Decision Support Systems: Applications

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V. K. Gusiakov

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Andrey Marchuk
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FORMENTOR REAL-TIME DECISION SUPPORT FOR RISK MANAGEMENT

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KEYWORDS: risk management, decision support,methodology, process control.

ABSTRACT

The supervision of complex industrial processes, such as in the chemical, nuclear or aerospace industries, is a difficult task. The FORMENTOR methodology allows the development of supervision support systems to aid operators in their tasks, especially when dealing with perturbations and hazardous situations. A FORMENTOR system presents a synthetic plant-wide view of the current situation, diagnoses the underlying causes of perturbations, predicts possible future evolutions and proposes remedial actions. For this the methodology integrates models, techniques and tools from four domains namely artificial intelligence, safety analysis, real-time computing and ergonomics. The methodological approach provides firm control over the development process while meeting the quality and technical requirements of the client; furthermore it ensures the reliability and maintainability of the obtained system

INTRODUCTION

The supervision of hazardous industrial processes is a difficult activity. Traditional process control techniques partly support the work of the operator. They can help in regulating and optimizing the process when the process is within known bounds. They do not give support however in the case of perturbations. The aim of the FORMENTOR project, which is part of the EUREKA program of cooperative european R&D projects, is to construct systems which help the operator when the process goes out of bound and perturbations or even hazardous situations occur. The ultimate objective of the project is to avoid perturbations that may lead to any type of loss: loss of production, start-up costs related to shutdown and in particular accident losses (Wilikens et al., 1993).

The development of a FORMENTOR system draws on techniques from four domains:

Safety analysis: safety studies are performed during the design stages of hazardous systems to show the relationships between failures such as component breakdowns, external events which include human actions, and feared events which could cause a certain loss. Until now the results of these studies are only implicitly transferred to the operators through a set of operating procedures and alarm management systems. The aim of FORMENTOR is to make this safety knowledge explicitly available to the operator.

Artificial intelligence: given the complexity of the plants and the number of potential perturbations AI techniques, such as heuristics and model-based approaches, are the most appropriate to provide support on time. A FORMENTOR system has to incorporate different types of knowledge, such as diagnosis knowledge to find the causes of observed symptoms and safety knowledge to detect and evaluate the current threats. We have chosen a knowledge based system approach, because it clearly seperates this knowledge from the reasoning processes using it.

Real-time computing: the supervisory support system is connected on-line to the target plant and has to take into account real-time constraints, such as the continuously changing plant conditions, deadlines and reactivity to external events.

Ergonomics: for the adaptation of the advisory system to the activity of the operators and for the acceptance of the system by them, ergonomics techniques play of course a crucial role.

The majority of currently available commercial products provides limited and partial support for the construction of advisory systems for operators. For example, AI process control tools are on the market which provide a diagnosis and simulation capability (see for example Årzen, 1992 for an overview). Common among these tools is a graphical, object-oriented and rule based programming environment. They provide a tool for defining the structure of the plant graphically, an object-oriented and rule-based programming environment, and a built-in simulator. One has to keep in mind however that these tools only support the design and implementation stages. They do not support the earlier stages of the development such as the analysis of the problem domain.

The methodology presented in this paper supports the construction of an industrial quality advisory system during the whole development process. For this it provides to a development team a complete set of models, techniques and tools. The way in which the methodology is constructed can be represented as a pyramid, as shown in Figure 1.

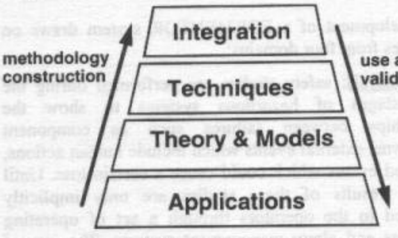

Figure 1: The Methodology Pyramid

First, we have identified pilot applications to obtain sufficient knowledge of the safety requirements in the supervision of hazardous systems (Section 2). We proceeded to develop analysis and design models to satisfy these requirements (Section 3). The models in their turn have been the basis for a set of techniques to support the construction process of an application (Section 4). Then we have integrated the models, techniques and tools in a methodological guide (Section 5). Finally, the pilot applications have served to validate the obtained results.

THE PILOT APPLICATIONS

Within the FORMENTOR project, one case study and two pilot applications have been constructed within the nuclear, aerospace and process industry domains:

The case study was concerned with the monitoring of a simulated Auxiliary Feedwater System (AFWS) of a nuclear plant. A prototype has been constructed which helps an operator to keep the plant in hot standby for as long as possible before proceeding to cold shutdown.

The first pilot application has as target process the on-ground filling process with liquid helium of an ISO-Satellite (Infrared Space Observatory). During the filling several hazardous situations can occur, such as the explosion of the vacuum vessel because of an overpressure or damage to instruments because of unacceptable temperature gradients imposed on the optics. An application has been developed for Aérospatiale which supports an operator in charge of the filling process.

The second pilot application has as target process a butadiene extraction plant. The plant is equipped with a process control computer, based upon feedback and feed-forward mechanisms which control the process when it is within known bounds. An application has been developed for British Petroleum which supports an operator when, as a result of a disturbance, the process deviates from the operating constraints. The system offers advice on the underlying causes and how to return to a state where normal control can be resumed.

Based upon the experiences with the pilot applications the following generic functions have been identified for a FORMENTOR system:

- monitoring: it validates sensor readings and detects symptoms which indicate an abnormal situation;
- diagnosis: it diagnoses the symptoms to deduce the underlying causes which have given rise to the abnormal situation;
- situation assessment: it assesses the current state of the target plant in terms of achievement of the plant goals and functions;
- consequence assessment: it predicts future situations and assesses the criticality of these situations; this also allows the operator to ask "what if" questions; and
- action planning: it determines the most appropriate sequence of actions to bring the plant back to a safer state.

The next section describes the theory and models which incorporate the underlying knowledge to provide the functions listed above.

THEORY AND MODELS

A safety-oriented supervision support system has to incorporate different types of knowledge of safety and plant experts. To integrate this knowledge efficiently in an industrial quality system it is necessary to use a structured approach. As a framework we have chosen the CommonKADS knowledge engineering methodology (Schreiber et al., 1993). According to CommonKADS, the development of a knowledge based system consists of the transformation of intermediary models. This breakdown diminishes the complexity of the development process. Each model corresponds to a specific concern, such as the organization, the tasks required, the agents involved, the experts' knowledge, and the design of the final system.

A distinction is made between the analysis and design activity. The analysis activity describes expertise at a conceptual level; the design activity on the other hand describes how this expertise can be realized as a knowledge based system. The advantage of having this distinction is that the expertise can be clearly expressed independently of implementation issues, which helps in constructing an understandable and maintainable system.

The Analysis Activity

One of the main outputs of the CommonKADS analysis activity is the expertise model, which models the expert's knowledge. The model makes a distinction between three different types of knowledge: domain, inference and task knowledge. The domain layer captures the knowledge of the application domain, such as the concepts, their properties, and the relationships between concepts. This layer also contains models of the target plant. The inference layer represents the reasoning process of the expert performing his/her task. Finally, the task layer specifies the reasoning tasks, their goals and the control over the associated reasoning processes.

To support the knowledge engineer constructing the expertise model we have developed the FORMENTOR task library. This library permits the speed-up of the analysis activity, because the tasks give the knowledge engineer a starting point to develop the expertise model for a new application. The library also provides the means of capturing the experiences gained in developing FORMENTOR systems for later reuse: when new applications are developed, the library is enriched accordingly. As an example, Figure 2 shows the FORMENTOR inference structure for the overall supervision support task.

The task library has been developed on KADS-TOOL workbench, an industrial workbench for the CommonKADS methodology, which supports a knowledge engineer in knowledge acquisition and the construction of an expertise model. The workbench allows the integration of the interviews with the experts and from these the extraction of concepts, attributes and relations. Based upon the interviews and the generic task library, the tool aids in the construction of the inference structures and the task layer of the expertise model.

To give to the operator diagnosis, situation assessment and prediction capability, we need to incorporate knowledge about the plant. A multi-model approach of plant models has been chosen to gather and represent this knowledge. This approach allows the knowledge engineer each time to focus in turn on each particular aspect of the plant. It also makes the obtained system easier to maintain because when changes are made to the plant, only the plant models have to be adapted. The models present different viewpoints of the plant, such as a functional safety-oriented view, a hierarchical component view, and behavioral views in normal and degraded conditions.

The main model which FORMENTOR proposes is the Goal Tree - Success Tree (GTST), which provides a functional safety-oriented view of the plant, relating high-level goals to hardware and process dependent functionalities. This model is used to show the criticality of the current situation by dynamically evaluating the plant goals achievement. The model also serves in selecting the most appropriate countermeasures to repair malfunctions related to the unachieved goals. The GTST originates from the work of Kim and Modarres (1987). Within the pilot-applications the model has been adapted to make it suitable for safety-oriented supervision.

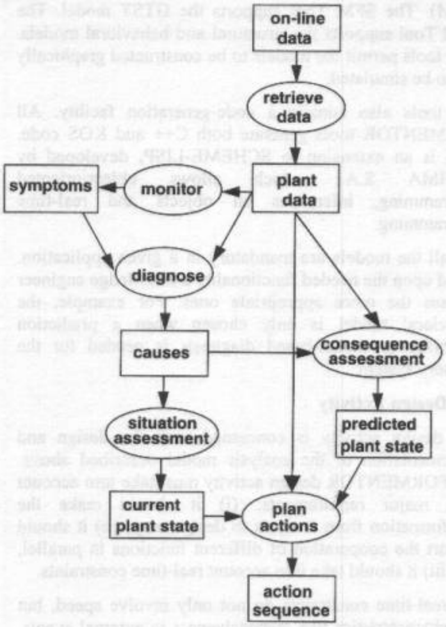

Figure 2: The inference structure for the overall risk management

Other models that are used are the plant structural model, the plant behavioral model, and the plant causal model. The plant structural model gives a component decomposition of the plant. This model presents the diagnosis results and is used as the underlying structure for the behavioral and causal models. The plant behavioral model describes the behavior of the plant. This model is used for model-based diagnosis and for the prediction of the future behavior of the plant. Finally, the plant causal models are used for a heuristical diagnosis based upon causal relationships. The models are inter-related. For example, a failed component of the structural model can be used as input for the evaluation of the achievement of a goal in the GTST.

The plant models have an analysis part and a design part. At the analysis level the plant models correspond to the domain models of CommonKADS, because they give to the knowledge engineer a certain viewpoint on how the domain knowledge should be structured. Unlike the domain models however, the plant models also have a design part, because they allow direct code-generation and they incorporate algorithms which allow the models to be manipulated in real-time. For this we have developed two software tools: the Safety and Functional Model Tool (SFM) and the Structural and Behavioral Model Tool (SBM). The SFM Tool supports the GTST model. The SBM Tool supports the structural and behavioral models. Both tools permit the models to be constructed graphically and to be simulated.

The tools also contain a code-generation facility. All FORMENTOR tools generate both C++ and KOS code. KOS is an extension to SCHEME-LISP, developed by SODIMA S.A., which allows object-oriented programming, inferences on objects and real-time programming.

Not all the models are mandatory in a given application. Based upon the needed functionality a knowledge engineer chooses the more appropriate ones. For example, the behavioral model is only chosen when a prediction capability or model-based diagnosis is needed for the advisory system.

The Design Activity

The design activity is concerned with the design and implementation of the analysis model described above. The FORMENTOR design activity must take into account three major requirements: (i) it should make the transformation from analysis to design easy, (ii) it should support the cooperation of different functions in parallel, and (iii) it should take into account real-time constraints.

The real-time constraints do not only involve speed, but also characteristics like responsiveness to external events, non-monotonicity and graceful adaptation. Though FORMENTOR systems respond to the characteristics of real-time systems, the time constraints are rather soft. Because the system is advising an operator there are always a number of seconds before a response is called for. The key problems are more in reasoning and adapting the advice in a changing world than in giving a fast response.

We have chosen an object-oriented approach as a basis of the design model, because features like encapsulation, code reuse and inheritance enable the rapid development of application modules which are understandable and maintainable (Schlaer and Mellor, 1992). Special constructs are needed however to take into account the real-time constraints. For this we have developed a data model which is based upon information propagation.

Information propagation is related to the need for a task to determine rapidly which objects are concerned by the modification of a given piece of information. This avoids reconsideration of all the objects after the modification of one of them. This concept is realized by structuring the objects in a fixed network, so that, after the modification of an object, information can be propagated directly to the objects which are concerned by the change.

The cooperation of different functions and the real-time constraints lead to a software architecture composed of independent modules which may run concurrently, if necessary on different processors. A module is then considered as a collection of objects and a local controller which manages the activity within the module. The overall system is in turn composed of a collection of modules and a global controller which manages the concerted activity of the modules.

The controllers have to ensure a reactive behavior of the system. To model this we have chosen the Statechart formalism which support a graphical specification of event-driven control (Harel et al., 1990). This makes the control accessible and easily modifiable. For example, a model-based diagnosis can take quite some time. When in between a more urgent problem shows up however, we want to be able to directly treat the new problem. Statecharts are very efficient for modelling this. They represent the control as state-transition diagrams with three additional features, depth, orthogonality and broadcast communication. These features ensure that the statechart specifications remain clear and concise for the description of a complex system.

To support the design activity we have developed two other software tools: the Data and Communication Management Tool (DCM) and the Statechart Design and Simulation Tool (SDS). The DCM Tool supports the graphical specification of modules, classes, objects, and information propagation structures. The SDS Tool supports the graphical specification of a statechart, provides consistency checking (such as non determinism and unreachable states) as well as a simulation environment.

TECHNIQUES

Until now we have described the theory and models part of the methodology, which explains in what way a FORMENTOR system should be modelled; another important aspect of a methodology however is to explain how this should be done. In the FORMENTOR methodology three different types of techniques have been developed: for the construction of the different models, for the re-use of safety analysis results and for the ergonomic activities.

The model construction techniques support the construction of the expertise model and the transformation from expertise to design model. Some of the transformations can be automated. The plant models for example can be directly translated into software code. This means that for these models a separate design representation is not necessary. For other knowledge in the expertise model this is not so simple however. An inference structure, for example, describes the reasoning process of an expert without taking into account implementation issues. This makes it impossible to automatically transform these into information propagation structures. We have therefore developed a design library of information propagation structures. The inference structures of the analysis library contains indexes to corresponding information propagation structures of the design library. For example, in the monitoring inference structure the inference step validate gives an index to information propagation structures of all sorts of sensor validation techniques, such as checking of process limits and stuck values.

The safety analysis techniques allow the re-use of the results of existing safety and reliability studies, such as Failure Mode Effect & Criticality Analysis (FMECA), HAZards & OPerability (HAZOP) studies, Fault-Tree analysis and Functional Block Diagrams. These studies incorporate a lot of information which can be used to construct the different plant models. The safety analysis techniques present which parts of the studies can be re-used and how.

Finally, the ergonomics techniques have been developed to incorporate a human-factors approach. Indeed, ergonomics plays a crucial role for the adaptation of the advisory system to the activity of the operators and for the acceptance by them. Having the right information available at the right moment is vital in order that the operator takes the appropriate actions as soon as possible when the process does not behave as prescribed. The methodology therefore integrates ergonomics techniques, which takes into account the needs of the operators, their activities, their characteristics, and their environment. The techniques encourage the active participation of the operators during the development. In particular, several prototypes are constructed during the development process, started as early as the requirements definition phase. These are used and evaluated by the operators themselves with the help of an ergonomist.

INTEGRATION: THE METHODOLOGICAL GUIDE

As the final step in the construction of the methodology we have integrated the developed models, techniques and tools into a guide. The aim of the methodological guide is to support a development team during the complete development process. It contains the following parts:

- a management part which aids the development team during the development process;
- a techniques library which contains the techniques for model construction, re-use of safety studies and ergonomics;
- a FORMENTOR task library which contains the inference structures for the analysis activity;
- a design library which contains the information propagation structures for the design activity;
- a plant model set which describes the different plant models: the GTST, structural, behavioral and causal models;
- a tool set which presents the developed FORMENTOR software tools;
- a living experiences part which describes the experiences with the developed pilot applications.

The management part shows a development team how to proceed in developing a new application. To support this it contains: a development task library and a management aid based upon the spiral life-cycle model.

The development task library supports the development team with a directory of all tasks which must be performed to ensure the quality of the system. The library is sub-divided into nine phases (such as requirements definition, functional specification, integration and validation) which themselves are sub-divided into about fifty tasks. For each task we define: an overview of the task, the activities needed, the inputs and outputs (such as documents and software code), the actors who intervene, and the models, techniques and tools which can be used. The directory gives an exhaustive list: for the development of a specific system not all tasks may be necessary.

Special care has been taken concerning the validation tasks of a FORMENTOR system. There are two possible approaches to this, the first one is using a dynamic simulator of the target process and the second one is to use scenarios of the real plant. The advantage of a simulator is that it can model many different sorts of perturbations without endangering the actual plant. A simulator has disadvantages however. First of all, the development of a simulator which simulates many different fault conditions is elaborate and costly. Secondly there is also the question of the validation of the simulator itself. It is difficult to guarantee that the simulator has the same behavior as the plant. This means that a FORMENTOR system which is validated against a simulator has to be re-tuned for the actual plant. At the moment we believe that it is better to validate against real scenarios of the plant. If needed these scenarios can be worked upon to simulate perturbations which cannot be performed in the real plant.

Finally, the spiral life-cycle model has been chosen to manage the development process. The spiral model breaks down the development process into several cycles which facilitates the construction of a complex system [Boe88]. At the beginning of each cycle the technical results which must be obtained at the end of the cycle are defined. Based upon these results a task-planning is constructed for the cycle. The tasks for this planning are then chosen from the development task library. The spiral model provides firm control over the development process and assures that the requirements of the client are met.

Together with the software tools the methological guide permits the development of applications with a minimum of delay and risk. The guide is backed-up with seven training modules, which cover all aspects of the methodology.

CONCLUSION

This paper presented the FORMENTOR methodology, which integrates models, techniques and tools for the construction of supervisory support systems of hazardous processes. The methodology is original in that it supports all aspects of the development process: theory and models, techniques, tools and the integration of these in a methodological guide.

For the knowledge engineering aspects the methodology is based upon CommonKADS, enriched with a FORMENTOR task library and specific plant models. The plant model approach is necessary for the development of a maintainable system, because when changes are made to the target plant, only the corresponding parts in the models have to be changed.

The design part of the methodology is specifically developed to take into account the real-time constraints. It is based upon an object-oriented approach, enriched with information propagation and propagation control. A design library has been developed to facilitate the transformation from expertise model to design.

Four software tools support the construction of the plant models, the propagation model and the statechart controllers. All tools have a code generation facility. This greatly increases the speed at which the system can be delivered.

Finally a methodological guide is constructed which integrates the developed models, techniques and tools. Furthermore it supports the management of the development process with a development task library and a spiral life-cycle model. The guide is backed-up with a FORMENTOR training.

Three pilot applications have validated the methodological approach. The project has now entered the industrialization phase and the methodology is currently applied in an industrial petrochemical application: a supervision support system for an industrial cracker.

ACKNOWLEDGEMENTS

We would like to thank all the members of the FORMENTOR project who contributed to the methodology.

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A LOCOMOTIVE WITH A STEERING WHEEL: RESPONSE PLAN DESIGN ISSUES

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KEYWORDS: response plan, modeling, probability, chemical accidents, risk analysis

ABSTRACT

Developing response plans for highly stochastic events is a challenging project. Emergency response planners must decide whether to spend their time developing a large number of plans in an effort to anticipate a wide variety of hazard behaviors or develop a smaller number of plans, assuming that hazard behavior is relatively predictable across a given span of time. Regardless of which approach is taken, planners must also decide on the degree of detail to which each plan is written. Should the plans be highly detailed so as to provide a more accurate assessment of the total response time and resources required, even at the risk of plan inflexibility, or should flexible, "generic" response plans be developed at the risk of underestimating time and resource demands? The use of risk analysis has suggested that a compromise is possible.

ISSUES IN RESPONSE PLAN DESIGN

What is the best approach to response plan design for emergency planners who must deal with stochastic hazards? Should a relatively large number of response plans be developed in the hopes of having a plan ideally suited for a given hazard, or should a smaller set of response plans be created in the belief that hazard behavior is adequately predictable over the time-scales involved? Having selected one of these philosophies, should the planner build plans which are very detailed or relatively generic?

The creation and availability of large libraries of response plans presents the problem of the time and expense involved in plan development as well as the possibility of response options "overload" should an event occur. As bad as not having a suitable response plan may be having too many to choose from. Smaller plan libraries reduce this potential problem but run the risk of not containing a plan suited for the hazard in question. Detailed plans provide more accurate response time and resource demands, but they may be inflexible in the face of a sudden change in hazard behavior. Finally, generic plans offer the benefit of flexibility at the risk of underestimating the time and resources required to respond.

Detailed response plans suffer the "locomotive" syndrome. They are guaranteed to get you to the place you *planned* to go, but you cannot steer them to the place you *want* to go if you change your travel plans. Generic response plans suffer the "automobile" syndrome. They can take you where you *want* to go, but without a detailed map and adequate resources you may never get there. What planners in this situation need is a locomotive with a steering wheel. The application of some basic risk analysis techniques suggests that this is possible.

CSEPP

There are eight sites in the continental United States where chemical agent weapons are stockpiled. The Chemical Stockpile Disposal Program was initiated in 1985, when Congress passed Public Law (P.L) 99145. This law mandated that the Department of Defense (DOD) destroy at least 90 percent of the entire stockpile by September 30, 1994. In 1990, P.L. 101-510 extended this date to July, 1999. The CSEPP was crated to assist military and civilian response meet this mandate. This program has provided significant support to military personnel at stockpile sites and civilian emergency response personnel in the communities near these sites in an effort to help them plan for the unlikely event of an accidental release of chemical or nerve agents.

For several years, IEM has been engaged in providing support for organizations involved in the CSEPP. One component of this support has been to assist these organizations in developing comprehensive, integrated response plans for their sites. In the course of this project, IEM analysts have discovered that there exist almost as many planning philosophies as there are emergency planners. Planners at some sites, because of site characteristics or basic planning philosophies, have chosen to create extensive and detailed libraries of response plans. Planners at other sites, for the same reasons, have chosen to create smaller plan libraries.

Our involvement with over twenty CSEPP jurisdictions and hundreds of response personnel has revealed that at least a partial solution to the dilemma outlined above is possible. If planners are willing to seek such a compromise, several options are available through risk analysis--one may reduce the number of conceivable hazards by deriving probability distributions, one may reduce the variant behaviors of this subset of hazards by conducting similar analysis of the factors affecting hazard behavior, and one may design response plans which contain both "generic" tasks (suited for any hazard that is likely to occur) and a smaller group of hazard-specific tasks. The first two elements of this approach have been applied at one CSEPP site.

CSEPP EVENTS

CSEPP events may be characterized as "low probability/high consequence" hazards. There are a variety of chemical agents involved in the CSEPP--some are vessicants, or blistering agents, such as mustard (HD); others are nerve agents. These agents may be stored in various quantities in a wide variety of munitions--from small land mines to large bulk containers. Some of the munitions contain explosive or propellant components while others do not. In short, there are a significant number of agent/munition combinations which will define the nature of a CSEPP hazard should one occur. Add to this the virtually infinite set of meteorological conditions which may exist at a CSEPP site and you may get an idea of the challenge faced by CSEPP planners and responders.

Nevertheless, the possibilities are not as endless as they may seem. For most sites, the mix of agents and munitions is quite limited. At one site, for example, a single agent type is stored in a single munition type. Other sites have increasingly heterogeneous mixes of agents and munitions; however, for a given site there will not be a maximum number of permutations of agents and munitions.

Another factor reducing the uncertainty for CSEPP planners is to provide them with insights into the likelihood of a given CSEPP event occurring at their site. This has been done through risk analyses conducted early in the CSEPP on a site by site basis. Not all conceivable CSEPP events are possible at all sites (because of agent and munitions configurations), and where certain CSEPP events *are* possible at a given site, these events are not equally likely. This alone reduces the scope of the task faced by local planners.

RISK ANALYSIS

The next step was to take the probability distribution of CSEPP events at a given site and combine the various source terms in question with local weather conditions to derive another distribution which indicates the probability of hazard behavior. IEM has provided this analysis to one CSEPP site.

Since CSEPP hazard behavior is defined in large part by meteorological conditions, IEM collected several years worth of National Weather Service (NWS) data for the site and subjected them to rigorous statistical analysis on a seasonal level. Given that no one can yet predict the weather with great accuracy, IEM was nevertheless able to derive a probability distribution for seasonal weather at the site using a statistical clustering algorithm. In essence, IEM analysts took weather parameters critical to CSEPP events (wind direction, wind speed, temperature, etc.) and looked for "clumps" in a multidimensional data array. IEM analysts then took the probabilities and profiles of CSEPP hazards for this site, applied the clustered weather data, and created a library of several hundred hazard cases. It should be noted that the site in question contains the most heterogeneous mix of agents and munitions so we may expect smaller hazard case libraries to obtain at other sites if this approach is used.

This library thus reflected *more likely* events combined with *more likely* weather conditions. This analysis also identified specific populations affected, evacuation time estimates for these populations, and hazard impact times. Overall, this project has allowed response planners at the site to focus their efforts on designing response plans for higher probability hazards and hazard behavior.

BUILDING RESPONSE PLANS

Having reduced the number of possible CSEPP hazards and reduced this subset even further by deriving a list of probable event behaviors, it has fallen to CSEPP planners to design their response plans. The CSEPP has provided military and civilian personnel at CSEPP sites with advanced decision-support systems. These systems include Gaussian dispersion models, evacuation modeling applications, relational databases for resource loading, and plan-building applications. These systems are integrated in a fashion that allows planners to create response plans that include resource demands, to validate these plans against "real world" resources, and to associate each plan with a given hazard profile. Thus, should an event occur, responders need only model the real hazard, select a hazard from their libraries that matches or approximates it, and an associated response plan will be recommended.

The degree of detail to which CSEPP personnel choose to write their plans may vary. As one might expect, the risk analysis described above reveals that planners at "remote" CSEPP sites will have more generic plans than planners at sites where significant civilian populations exist. This is because changes in the factors involving hazard behavior are less likely to affect the potential impact of the event. Nevertheless, by reducing the overall number of hazards at a site, we may significantly reduce the burden to CSEPP planners.

EVALUATING RESPONSE PLANS

Again using risk analysis methods, response plans may be tested against the complete library of hazard cases for a given site. All response plans suffer from one limitation--the durations associated with each task in the plan are estimated and fixed. Usually, plans are modeled and a "total response time" is derived by summing the durations of tasks critical to migrate from hazard perception to public alert and protection.

As we know, plans are rarely so well behaved or accurate when put into action. A truly infinite number of factors now enters the response equation and tasks that were scheduled to take, for example, ten minutes may take twenty (or five). In short, a method is needed to build dynamic response models.

Using a risk analysis tool known as Crystal Ball©,[1] analysts at IEM have begun a project which seeks to test response plans in this fashion. This application uses the Monte Carlo method to assign random task durations to a plan, with these random values falling within certain probability distributions. For example, we may build a model that has a given task, say "run the hazard model", taking five minutes. We may then assign a "normal" distribution to this task which indicates that the task may take as little as three minutes (assuming users familiar with the use of the hazard model) or as much as fifteen minutes (assuming users less familiar with the model). We continue to assign durations and distributions to response plan tasks, and when we run the simulation, we derive a "total response time" figure that, we feel, is much more realistic than simply the sum of estimated and fixed task durations. Furthermore, sensitivity analysis can be conducted on the model to determine tasks which are critical for effective response.

We have already discussed the creation of seasonal libraries of hazard cases. Using the same simulation software we can also derive a "mean hazard impact time" for the entire seasonal case library. Obviously, we may compare the derived total response time noted above and the mean hazard impact time to determine a confidence interval for each plan. This can serve as an important benchmark for CSEPP planners seeking to refine their plans. Should this evaluation reveal low confidence intervals for certain plans, the process of modifying these plans--making them more or less detailed or increasing the number of available plans--becomes a manageable process.[2]

CONCLUSIONS

Risk analysis can significantly reduce the challenge faced by emergency response planners. Developing a compromise on the need for large and/or detailed libraries of response plans with smaller, more generic plans is an ongoing effort.

The effectiveness of the risk analysis discussed in the section on evaluating response plans remains to be seen. IEM analysts feel confident however, that this approach represents a new and exciting means of subjecting plans to rigorous testing through simulation.

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[1] Crystal Ball©, is an risk analysis application developed by Decisioneering, Inc.

[2] Presentation of this paper at TIEMEC 1995 included a brief demonstration of how response plan assessment is being conducted by IEM analysts.

AN INTEGRATED PC-BASED RESEARCH AND INFORMATION SYSTEM FOR TSUNAMI RESPONSE AND MITIGATION

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KEYWORDS: tsunami, mathematical modeling, databases, risk assessment

ABSTRACT

As a result of a feasibility study, a concept for and a prototype of the Integrated PC-based Tsunami Research and Information System (ITRIS) was developed at the Tsunami Research Group of the Novosibirsk Computing Center, Russian Academy of Sciences. This concept is based on the integration of numerical models, observational and reference data, processing and analyzing tools, along with visualization and mapping software embedded inside the specially developed graphical shell providing the ability for fast and efficient manipulation of maps, models and data. The ultimate goal of the ITRIS Project is to develop an enhanced environment for IBM PCs and compatibles for the retrieval, visualization, and processing of data as well as for carrying out basic numerical experiments in the investigation of different aspects of the tsunami problem without the need for additional coding. The final product could be used not only as an interactive modeling system, but also as a convenient electronic textbook and reference book on tsunamis.

INTRODUCTION

A tsunami is a terrible disaster for a significant portion ofthe coasts of the Pacific and some other seas. In terms of the total damage and potential loss of lives tsunamis do not rank first among other natural hazards. Actually, they are fifth after earthquakes, floods, typhoons and volcanic eruptions. However, they have an extremely adverse impact on the socioeconomic infrastructures of a society. This is an impact which is strengthened by the suddenness of onset and widespread destruction of property and the high percentage of fatalities among populations exposed to a tsunami. The significance of this hazard has been increased in the last thirty years by the rapid growth of population and fast development of the coastal areas in many countries.

Numerical methods have been long and successfully used for mathematical modeling of tsunami generation, propagation and runup. The ability of numerical models to reproduce the basic features of this complicated natural phenomenon has been more than once demonstrated by the computer simulation of many historical tsunamis. However, up to now their application to the operative tsunami prognosis has been somewhat limited. This can be explained in three ways: first, the lack of time for issuing warnings in case of regional events; second, the lack of computational facilities in the existing tsunami warning centers; and, third, the lack of operational data on earthquake source parameters. At present, the first two reasons can be eliminated due to the development of new and effective numerical algorithms and, even to a greater extent, by a fast increase in the power of micro- and personal computers that are now available at the regional warning centers.

As a result of a feasibility study, the concept of the Integrated Tsunami Research and Information System (ITRIS) has been developed at the Tsunami Laboratory of the Novosibirsk Computing Center. This concept is based on the application of numerical models for the prediction of tsunami heights along the coast by implementation of a specially elaborated interactive computer technology that provides near real-time calculation of tsunami generation, propagation and run-up. This system also facilitates the interpretation of data and enhances the decision-making process through an intensive application of computer graphics, mapping and data analysis.

BASIC SYSTEM REQUIREMENTS

In elaborating the ITRIS we plan to meet the following basic requirements:

(1) it should be able to simulate all three basic stages of a tsunami - generation, propagation and run-up - and should be easily customized to any tsunamigenic regions of the Pacific and elsewhere;

(2) it should be applicable in the operational mode which means that numerical modes and algorithms should provide computational time less than the actual propagation time (typically 20-30 min);

(3) the system should have a modular structure allowing flexibility and adjustment to a particular application as well as be an open system providing the growth potential to keep abreast of research advancement;

(4) the system should have built-in comprehensive databases containing all the meaningful information related to the tsunami problem for the particular region;

(5) the system should have built-in computer mapping software providing the ability to display results and data on actual geographical bases;

(6) the system should have a friendly user interface based on a menu-driven approach.

The ultimate goal of the ITRIS Project is to develop an enhanced environment for IBM PCs and compatibles for retrieval, visualization and processing of data as well as for carrying out various numerical experiments in the investigation of different aspects of the tsunami problem without the need for further coding. The final product could be used not only as an interactive modeling system, but also as a convenient electronic textbook and reference book on tsunamis. The product may also be used as a computer-aided device for investigation of different aspects of tsunami problem including the long-term assessment of tsunami risk for particular region.

BASIC SYSTEM FUNCTIONS

The basic functions of the system are as follows:

(1) choice of an area for numerical experimentation within the Pacific region and automatic construction of the computational grids;

(2) computation of the initial displacement in the tsunami source on the basis of preliminary selected or operationally estimated earthquake source parameters;

(3) fast computation and plotting of the tsunami travel time charts with the generation of a list of travel times for the initially indicated points;

(4) computation of full dynamic tsunami wave field (displacement of water surface, components of particle velocity) at each "sea" grid point of the computational area;

(5) computation and plotting of tsunami wave forms at any indicated point of the computational grid;

(6) computation and plotting of the distribution of the maximum tsunami heights along the coast;

(7) computation and plotting of 3-dimensional pictures of the tsunami wave field at any given moment in time;

(8) retrieval and display of historical data on regional seismicity and tsunamis for any particular area of the Pacific.

FIELD OF APPLICATION

ITRIS is being developed for three basic application fields:

(1) in the regional tsunami warning centers in event-mode for the operational wave height prediction and the facilitation of decision-making process. This is to be achieved through intensive application of formalized expert knowledge in the field. The system is also designed for use at these sites in the pre-event mode for simulation and "playback" of possible warning situations, and for personnel training;

(2) in the governmental and non-governmental agencies responsible for tsunami mitigation efforts as inexpensive PC-based device for in-depth education and orientation of officials, public demonstrations and pre-event emergency planning;

(3) in research centers as an advanced computer-aided tool for carrying out numerical experiments for investigating different aspects of the tsunami problem.

MATHEMATICAL MODELS

As a model of the tsunami generation we use a dimensional dislocation model of an earthquake source placed within the homogeneous elastic halfspace. This conventional earthquake source model is described by six parameters: length of the fault plane L, width of the plane W, depth of the fault h, dip-angle d, strikeangle l and the amount of displacement D. The intensity of this source is represented by its seismic moment which is a product of rigidity of the medium, the area of the fault, and the amount of displacement over it. The vertical static displacement produced by the dislocational source is calculated by the algorithm described in (Gusiakov, 1978) and used as the initial condition for the tsunami propagation program.

If there are no operational data for the source mechanism, it is possible to input the tsunami source as a simple elliptical elevation with parameters (length, width and vertical elevation) defined by some correlation formula with the source magnitude.

The non-linear shallow water system is used for the modeling of tsunami propagation in a water layer with variable depth. This system is solved numerically by a specially elaborated algorithm based on the so-called splitting method and application of variable computation grids. An algorithm of this type diminishes computer time 5-6 fold in comparison with the conventional finite-difference methods and allows us to use a 32bit PC instead of a mainframe computer for near-real time tsunami calculation (Gusiakov, Marchuk, Titov, 1992).

The algorithm of the travel time computation is based on the calculation and comparison of travel times between the neighboring grid points over a 16-ray star (Marchuk, 1988). As compared to the conventional ray method for calculating travel times charts, this algorithm has a higher efficiency and stability in the regions of complicated bottom topography. On 66-Mhz 486 PC, it allows us to obtain a 1-hour travel time chart in several seconds of CPU time.

DATABASES

The built-in database is intended to be a comprehensive source of observational data on historical tsunamis in a particular region along with some additional reference information related to the tsunami problem.

At the moment the database consists of four basic parts:

1) EARTHQUAKES database contains the source data of regional earthquakes down to magnitude 4.0. Source information includes date, time, coordinates of epicenter, depth, magnitude (basically Ms), and seismic intensity followed by indexing to source data. All data can be cross-correlated and retrieved by geographical area, date, depth and magnitude.

2) TSUNAMIS database consists of four main parts: detailed source data of tsunamigenic events, coastal observation of wave heights, original description of tsunamis, and bibliographical references. Source data of tsunamigenic events are cross referenced to the earthquake database but contain the extended set of magnitudes including moment-magnitude Mw, tsunami-magnitude Mt, seismic moment, moment-tensor and source mechanism (where available), tsunami intensity, maximum run-up height, validity of event, warning status and some other complementary information. The tsunami data can be retrieved by area, date, source magnitude and tsunami intensity. The information can be output in summary (condensed) or detailed (expanded) form.

3) BATHYMETRY database contains the digital bathymetry on the regular grids. This database has a hierarchical structure which consists of three main levels. The first level contains the bathymetry for the whole Pacific on a 5-minute grid. These data are used for computation of trans-Pacific tsunamis and for visualization of observational data on small-scale maps. The second level contains the regional bathymetry data on a 1-minute grid which are used for computation of regional tsunamis. The third level contains the most detailed data on coastal and bottom relief on 0.1-0.01-minute grids. They are available only for some particular areas within the region where the modeling of run-up processes and interaction of tsunamis with harbors are necessary.

4) GEOGRAPHY database contains geographical data stored as different layers such as geographical contours, isolines of depth and surface elevation, administrative and state boundaries, rivers and lakes, and main cities. The user can interactively build-up the contour background map of a selected area with any desired degree of load and detail.

USER'S INTERFACE

The ITRIS is being developed for the user who is not a professional in applied mathematics and computer science. This requirement has predetermined the development of the special user interface based on pull-down and pop-up menus having on-screen buttons for process management and on-screen windows for input and output of information. A specially elaborated graphical shell provides the ability to manipulate maps, models, data and the results of computation in an efficient and convenient manner. The results of a computation can be output on the screen as graphics, histograms, isolines and vector fields which are overlaid on the real geographical maps.

Some examples of screen outputs provided by this graphic shell can be seen in Figs.1-6.

EXAMPLE OF APPLICATION

The prototype of the ITRIS has been developed for the KurilKamchatka region; however, at minimum cost it can be customized to any other region of the Pacific and elsewhere. The following example shows its application for the numerical simulation of a real historical tsunami in the New Guinea area. This is one of the more active tsunamigenic areas in the whole Pacific Fire Ring. Within two weeks in July of 1971 in the Solomon Sea there were two strong tsunamigenic earthquakes with magnitudes near 8.0. The example shows the result of the application of the ITRIS software for the simulation of the first event with magnitude 7.8 as occurred on July 14, 1971. The headpiece of the system consists of the background map of the Pacific and the main menu panel. The buttons on the panel corresponds the basic program blocks of the system. REGION opens the sub-menu for the selection of the region for numerical experimentation and construction of the computational grids. SOURCE provides the computation of initial bottom displacements for the dislocation or double-couple seismic source. WAVE - the core of the system - provides the simulation of tsunami propagation within non-linear shallow water model. TRAVEL TIMES provides fast calculation and plotting of tsunami travel times charts. DATA opens the access to the built-in historical earthquake and tsunami databases.

Fig.1 shows the submenu of the second level (the extension of the REGION button). The button CHOOSE AREA is activated and provides the selection of an area for numerical experimentation within the region (South-West Pacific) shown in the upper left screen window. The next step is the construction of the computational grid. It is made with the help of subroutine GRID (Fig.2) which takes the initial bathymetric data from the BATHYMETRY database and constructs the grid with variable spatial steps using several parameters input by the user through on-screen windows.

The next step is the calculation of initial bottom displacements in the source area, which is made through the sub-menu SOURCE. For this simulation, we use the dimensional dislocation model of the seismic source with parameters taken from (Schwartz, Lay, Ruff, 1989). Fig.3 shows the isolines of vertical bottom displacement (within the left window). These are used as initial conditions for the tsunami propagation program. During the computation, the current wave amplitudes at the preliminary selected coastal points (shown as circles with numbers on the map of an area) can be seen in the right screen window.

The specially developed numerical algorithm, based on the socalled splitting method, provides the ability to calculate tsunami propagation even on a personal computer faster than actual travel time. For instance, this simulation on 83 minutes of propagation time takes about 45 minutes of processing time on a 20-Mhz 386 PC. If we need to obtain the tsunami travel times only, we can go directly to the TRAVEL TIME lock, which provides the capability for quick (in a matter of seconds) calculation of travel time charts and displays the list of travel times to preliminary selected points (Fig.4).

An example of computed wave forms is shown in Fig.5 for point No. 1 (near Rabaul City) along with the actual observation of this tsunami recorded by mareograph near this point.

And the last figure (Fig.6) shows 3-d view of tsunami propagation at four different moments in time. According to the historical catalog, the most serious damage during this tsunami occurred on west coast of Bougainville Island (island on the right) where highest run-up (up to 6.5 meters) was observed. One can see that the numerical model, in general, reproduces this feature.

FUTURE DEVELOPMENT

The future development of the ITRIS supposes its specialization in three basic directions:

(1) facilitating the decision-making process at the regional Tsunami Warning Centers (TWC),

(2) education and training of the personnel of TWCs as well as other officials responsible for the tsunami mitigation efforts,

(3) automatization and facilitation of numerical experiments in tsunami research and investigation.

The design goal for the first application is the development of the Tsunami Expert System (TES) which can facilitate the decision making process in the emergency mode in the regional TWCs thorough integration of various types of observed data, mathematical models and intensive application of formalized expert knowledge in this field. In the operational mode, the expert system integrates all relevant information in order to evaluate the immediate tsunami threat and to suggest appropriate actions for the duty personnel. In the pre-event mode, the system allows investigation of the potential tsunami impact within the area of responsibility and provides realistic model data for planning appropriate emergency actions.

Within the second application, the design goal is the development of the Computer Aided Device for Education and Training (CADET) which will provide the possibility of numerical simulation of various warning situations within particular regions. At tsunami warning centers, the CADET system can be used for the development and playback of possible scenarios of tsunami actions within their regions of responsibility and for routine training of the duty personnel for emergency operations. At governmental and non-governmental agencies responsible for tsunami mitigation efforts, the system can be widely used for in-depth education and orientation of officials, for public demonstrations and for preevent emergency planning.

The third application of the ITRIS development foresees the elaboration of the Interactive Tsunami Modeling System (ITMS) which can be used as an advanced computer-aided tool by scientists who are not professionals in applied mathematics or computer science but who need to do some numerical experiments in tsunami research and investigation. It will provide some standardized software for tsunami modeling combined with extensive databases and efficient data processing algorithms embedded inside the convenient user shell. The system will have its basic application in tsunami research centers, and its main product will be the formalized expert knowledge applicable for tsunami risk assessment and mitigation.

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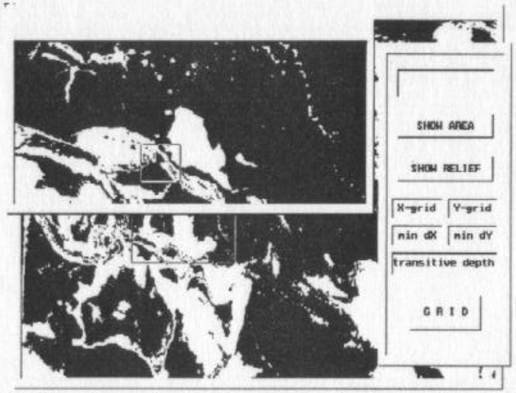

Fig.1. Selection of the region (Southwest Pacific) for the numerical experiment. Using the moving screen window shown in this example within the Solomon Sea the user can select an area for tsunami simulation and retrieve bathymetric data from the regional data base.

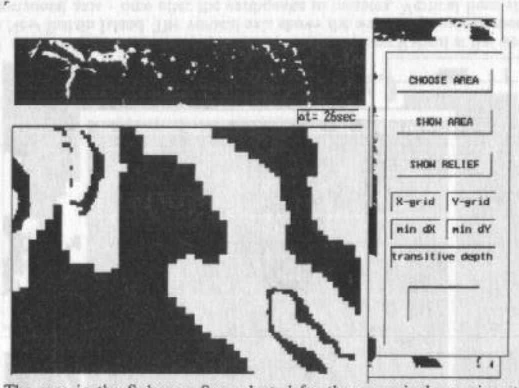

Fig.2. The area in the Solomon Sea selected for the numerical experiment. The program AREA retrieves bottom topography from the bathymetric database and constructs a computational grid with parameters to be input through on–screen windows on the right menu panel.

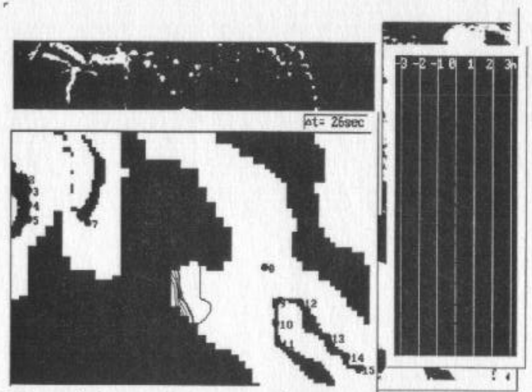

Fig.3. The vertical static displacements of the ocean bottom calculated by the subroutine SOURCE for the source parameters of the 1971 (July 14) event which were taken from (Schwartz et al, 1989). On the right - the current distribution of tsunami wave heights at the selected points indicated by the circles on the map in the left screen window.

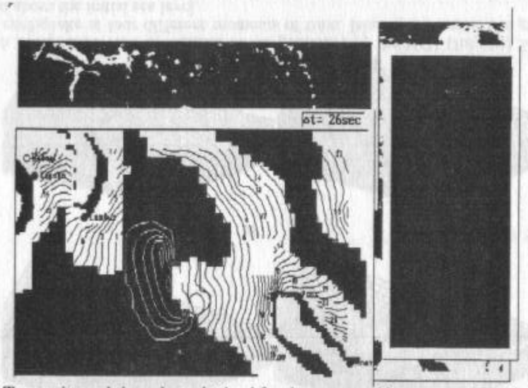

Fig.4. Tsunami travel time chart obtained for the source with parameters of the 1971 (July 14) Solomon Sea tsunamigenic earthquake (Ms = 7.8). Digits near the isolines show the travel time in minutes. The list of travel times of the front wave to the preliminary selected points is shown in the right screen window.

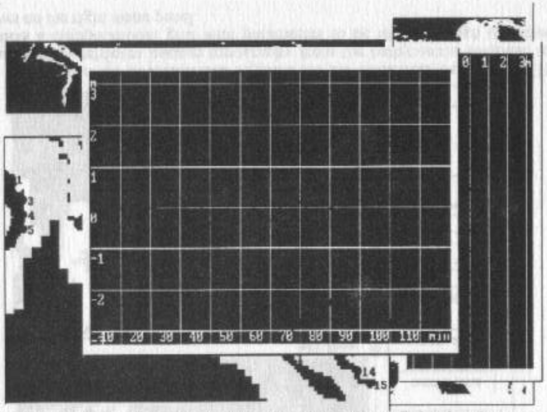

Fig.5. Computed wave form at point number 1 located near Rabaul at the west coast of he New Britain Island. The vertical axis shows the wave amplitude in meters and the horizontal axis - time after the earthquake in minutes. Vertical lines show the actual observations of wave heights.

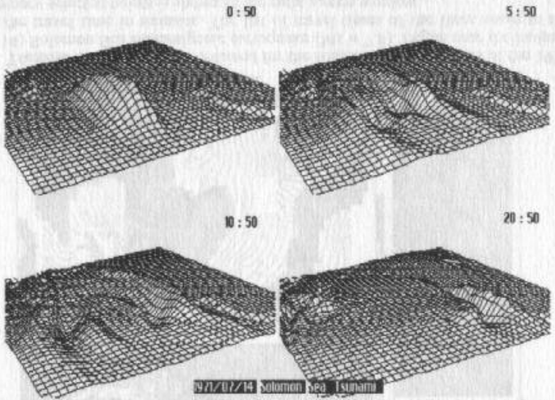

Fig.6. Perspective view of tsunami waves generated by the 1971 (July 14) Solomon Sea earthquake at four different moments of time. Islands are marked in gray and lifted above the initial sea level.

TIEMEC '95

Safety Issues in Emergency Management

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DEVELOPMENT OF SCIENTIFIC PRINCIPLES FOR ENGINEERING SAFETY

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KEYWORDS: safety, technical systems, disasters, life time, strength, fracture mechanics.

ABSTRACT

The analysis of technogenic and natural catastrophes that occurred over the last decades shows that further scientific and technological civilization development has become impossible without a comprehensive approach to engineering safety.

On the basis of this research in addition to existing norms and standards, special problems of safety and catastrophe analysis are worked out. This experience is primarily accumulated in the atomic, space and aircraft industries.

Further development of science & technology progress, implementation of large-scale projects and preservation of an ecologically sound environment will entail a risk of origination of technogenic, natural and natural-technogenic catastrophes causing regional, national and global consequences. Due to present tendencies in the development of Russia such a risk will exist even in case of military threat reduction. These problems are a main subject of the Russian state scientific and technical program, "The Engineering Safety."

Major accidents and catastrophes occurring in Russia and abroad (in the USA, FRG, Great Britain, Italy, Japan, Norway, India, Mexico) in the last decade have caused thousands of human losses. According to UNO data, about 2,8 mln. people perished and 280 mln. were injured due to natural calamities in the last 20 years. Serious damage has been caused to the environment. Direct economic losses and expenditures for liquidation of natural calamities' consequences have reached tens of billions of dollars.

Nowadays many thousands of potentially hazardous facilities are still in operation in all the continents of earth, which contain radioactive substances, toxic agents, and explosives, which are enough to cause grave damage to the environment and even to completely annihilate life on earth in case of accidents and catastrophes. There are about 50 nuclear and hydrogen combat charges and about 10 nuclear reactors at the bottom of world oceans as a consequence of accidents and catastrophes happening at military sites. The actual probability of grave accident generation (with core melting) at NPPs (the quantity of reactors is about 400 now) is more than 10^{-4} per reactor per year instead of the required and acceptable 10^{-6} - 10^{-7}.

Substantial risk increase in Russia and abroad is related to the fact that the most hazardous technical systems have been located, as a rule, within areas with a dense concentration of population.

As has been revealed by analysis of reasons and consequences of major accidents and catastrophes in Russia and abroad, complex technical systems which present a real danger to people and environment are designed and manufactured, in most cases, using traditional design rules and simple engineering calculation/test methods. Unfortunately, in Russian and foreign practice there are no fundamental scientific principles thoroughfully formed for promoting safety of technical systems, people and the environment according to risk/survivability criteria under badly damaged conditions; national and international guidelines with norms and regulations on accidents' classification (predicted/unpredicted/hypothetical accidents) and their consequences (regional/national/global consequences) aren't compiled yet; general requirements for hazardous operating processes, technologies, materials and technical sites aren't developed either; there are no worked out unified basic provisions on rigid and functional protection systems and emergency monitoring using mobile ground, aerial and space systems; and state technical complexes for liquidation of accidents/catastrophes' consequences have not been created.

Further development of complex technical systems within a lifetime ranging from seconds (rocket-space vehicles) to 50-100 years (nuclear reactors, engineering facilities), without regard for new safety criteria which characterise these systems' transition to final conditions threatening people and the environment, should be considered unacceptable. Quantitative substantiation for conditions of emergency origination should be calculated not only for normal operating conditions, but also for extremal ones which are caused by fractures, explosions, fires, leakages of radioactive and toxic substances, earthquakes, hurricanes, tsunami, aircraft and space vehicle crashes, or subversive actions.

Safety assurance problem will be of vital importance for the nearest decades in Russia due to expiration of the lifetime of a large number of power units (including atomic ones), chemical and transportation apparatuses, complete replacement or modernization of which requires significant financial and intellectual expenditures.

A great diversity of approaches to complex technical systems' safety is first of all conditioned by the distinctive features of various systems and, naturally, by a statement of local problems for such systems' safety. The absence of a general concept for complex technical systems' safety, which would allow us to carry out unified analysis and to develop scientific criteria for safety assurance standards, can be explained by the aforementioned facts. That's why the main objective is the generalization of fundamental research development and creation of unified scientific principles of safety analysis and safety assurance standards. The following classification of these objects is offered to your attention, which takes into account their design structural peculiarities and the level of potential hazard to people and the environment in case of technogenic and natural catastrophe generation:

- nuclear power engineering sites;
- chemical plants;
- special equipment (rockets, space vehicles, computer-aided systems);

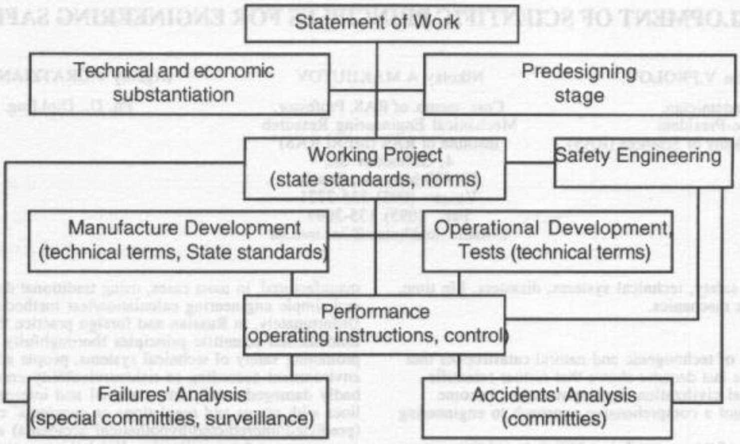

Fig. 1. Structural scheme of technical facilities' development

- unique engineering structures;
- civil engineering sites;
- traditional and non-traditional power engineering sites;
- objects of machine building and metallurgy industries;
- transport systems;
- main pipelines;
- equipment for operation in low temperature conditions (Arctic equipment).

While establishing these unified research principles one should take into account the potential hazard level of this or that object, types of catastrophes and emergencies (regular operational conditions, deviations from normal operating conditions, predicted/unpredicted accidents, hypothetical accidents), affecting factors' assessment, and comprehensive safety criteria systems.

The main goals of fundamental and applied development should be multicriteria safety substantiation (using relevant assessments, modelling, stand simulation, and full-scale tests) for complex technical facilities both of civil and military destination at the design/manufacture/ operation stages. It turns out that modern safety requirements raise the cost of a project and the complexity of its realization to such an extent that it would be expedient to cancel it; though in this case acting traditional norms and requirements can be fully satisfied.

Safety assurance problems are solved according to the most frequent principle within the frames of present design norms and regulations for the majority of complex technical sites—it is assumed in projects that provided acting norms are met, then there is no need to carry out special safety analysis (Fig. 1).

Development of a statement of work, feasibility study, and predesigning are performed, as a rule, without regard for safety requirements, or taking them into indirect account. There is no special consideration for the question of accidents and catastrophes in the statement of work. At the working project stage principal structural schematics and working drawings are developed using basic requirements for standards, norms and other technical documentation as well as safety engineering norms for operators under normal operating conditions; or, deviations from them are foreseen. Manufacture, operational development, adjustment and tests are carried out in accordance with technical terms and standards; additional safety analysis is not conducted at this stage.

Performance of new and acting facilities is executed according to pertinent operating instructions with arrangement, if necessary, of technical control and certification procedures. Operating failures are registered by special departmental committees or surveillance services. Major accidents and catastrophes are investigated by special interdepartmental committees and surveillance bodies. According to the results of investigation accomplished by these bodies design and technology solutions are adopted which are directed to avoiding new failures and accidents. As well, changes are introduced into safety engineering instructions. Practically all branches of machine building, construction and power engineering, and the transport industry are operating according to this scheme.

While developing a general structure of basic safety norms for complex technical systems it is necessary to consider:
- hazard level of a complex technical system;
- types of emergencies;
- comprehensive set of affecting factors;
- safety criteria system.

Project and design requirements of the upper level are developed based on fundamental provisions of development of complex technical systems which in the majority are common to all types of structures for all countries. Fundamental provisions of the complex technical systems' concept are stated in different documents of design offices, firms, institutes, and state associations.

As regards the aforementioned facts, the structure of safety norms and regulations for complex technical systems should be compatible with the present structure of norms and regulatory rules for design, manufacture, operational development and tests of sites and systems. As compared to theconventional practice of complex technical systems development, new stages of work on safety issues should be introduced (Fig. 2).

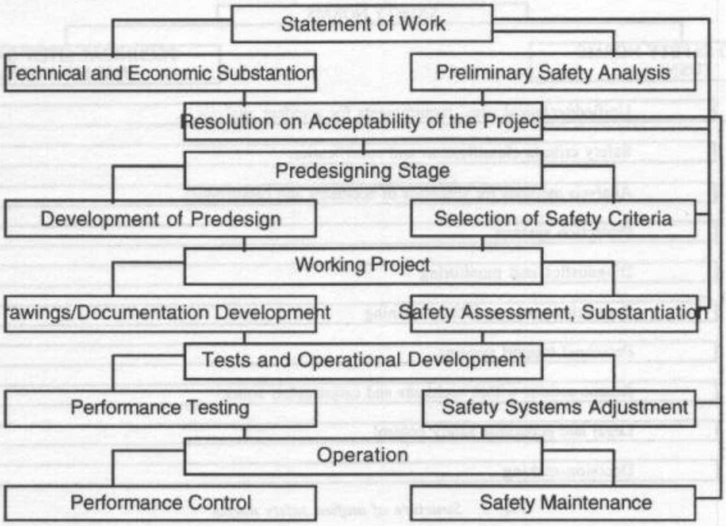

Fig. 2. Structural scheme for complex technical systems' development

Relevant safety requirements for a designed system should be included in the Statement of Work for the project. These requirements will be further developed in the course of safety works, transferring to their direct quantitative wording. At the initial stage of work while compiling the statement of work, preliminary safety analysis has been done.

A resolution on acceptability of a project from the point of view of safety is of exclusive importance. Adoption of such a resolution should be exercised at all further stages of complex technical systems' development. As Russian and foreign experience confirms, in the case of absence of adoption of a resolution on acceptability of a project on safety norms and criteria, it could be possible to implement any project, provided it met all other norms in force.

At the predesigning stage one should include the formation and specification of criteria and methods for providing safety into the documentation of this stage.

At the working design stage safety substantiation should be conducted including mathematics and physical emergencies' modelling together with working drawing preparation.

At the operational development and tests stage, there will be comprehensive elaboration of systems to ensure safety together with experimental performance tests which reveal whether the real system's characteristics meet the requirements of the statement of work.

As regards the operation stage, operating control over the state of complex engineering facilities has been foreseen using pertinent diagnostic methods within the framework of conventional development of complex technical systems. In compliance with the developed safety concept, possibilities for efficient emergency response to catastrophes' origination, using monitoring and diagnostic means, should be included in the concepts of operation of complex technical sites which may cause potential hazards. Support of the designed safety level should be based on both deterministic approaches and on probabilistic ones.

Thus, the right-hand branch of the structural scheme of complex technical systems' development depicts the necessity of considering safety assurance issues at all the stages of project development. Regulatory and surveillance bodies should have the right to participate in adoption of resolutions on project acceptability from a safety point of view.

In those cases when a complex technical system project is prepared on the whole, or only some part of it is prepared, but the project itself hasn't been commerciallized yet, safety factors should be considered in the same volume as the statement of work, predesigning, and working design development stages for a new project development.

Owing to the comparative stability of general mechanisms of emergency propagation at various types of facilities, it would be advisable to foresee two levels of safety norms and standards, while forming a structure of general safety norms (Fig. 3):

- unified safety norms - USN (for main types of objects) ;
- technical sites' safety norms - TSSN (for the given type of object).

The first chapter of materials on USN should contain the following:

- general requirements for safety analysis of objects;
- determination of potential hazard level for objects;
- classification of emergencies according to their technological, economic, social, political, and ecological basic consequences;
- classification of accident types according to the reasons of their initiation;
- classification of accident types according to probability level of their outburst;
- classification of accidents' character according to relevant groups of affecting factors.

As regards the second chapter of materials on USN, it should contain classification and specifications of both qualitative and quantitative safety criteria. Quantity and

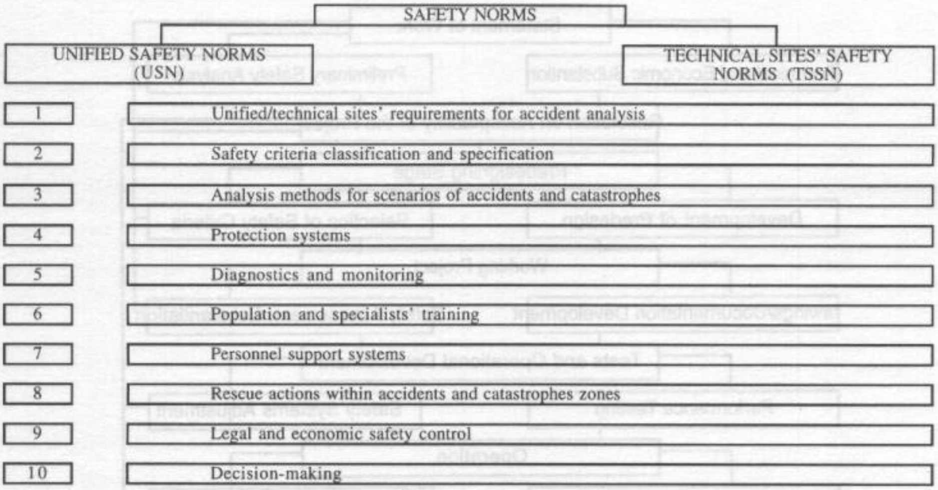

Fig. 3. Structure of unified safety norms

combinations of required criteria values should be related to classes, types and character of accidents and catastrophes.

As regards the third chapter of materials on USN, it should contain analysis methods of initiation and propagation terms for emergency scenarios from the point of view of modern fundamental science. The major attention should be paid to mathematics and physical modelling for emergency propagation and pertinent response to it.

As regards the fourth chapter of materials on USN, it should contain general information on selection of emergency protection systems for the population, the environment and technical sites.

As regards the fifth chapter of materials on USN, it should contain general requirements for objects' diagnostics and monitoring, not only in regular situations but also in emergencies. The diagnostics should cover technical facilities, their personnel, the population and the environment.

As regards the sixth chapter of materials on USN, it should contain general requirements for training methods for the population and specialists' response in emergencies (at accidents' initiation and propagation stages).

As regards the seventh chapter of materials on USN, it should contain systems and means of support, training and retraining of operators at potentially hazardous facilities.

As regards the eighth chapter of materials on USN, it should contain emergency response measures for personnel, the population, and search-and-rescue services for localization of accidents and liquidation of their consequences.

As regards the ninth chapter of materials on USN, it should contain requirements on legal and economic safety control.

As regards the final chapter of materials on USN, it should contain general recommendations on decision-making at local, governmental and international levels in emergencies and in the course of liquidation of their consequences.

Concerning materials on technical sites' safety norms (TSSN), they should contain:

- a list of basic distinctive features of potentially hazardous objects;
- chosen class, type and character of accidents and catastrophes;
- quantitative and qualitative safety criteria;
- recommended assessment methods for prediction of probable emergency propagation;
- diagnostics and monitoring methods for objects and the environment in usual situations and in emergencies;
- population and specialists' training for emergency response measures;
- personnel life-support methods and means in emergencies;
- measures on protection of operators, the environment, and technical sites;
- recommendations and requirements for actions to be undertaken in emergency areas;
- legal and economic standards for safety control; and,
- recommendations on decision-making at relevant levels.

Thus, while developing the above unified scientific principles of safety standards, there should be taken into account: the potential hazard level of the objects, types of accidents and emergencies (regular operating conditions, deviations from normal operating terms, predicted/unpredicted/hypothetical accidents), a comprehensive safety criteria system, and affecting factors' assessment.

The International Institute of Engineering Safety (IIES) was organized on the basis of the national program, "The Engineering Safety," by representatives of public and scientific organizations of Russia and some other countries; it is an effective instrument in realizing international cooperation on the above mentioned tasks in ensuring safety in designing and maintaining potentially dangerous facilities.

The IIES is established by representatives and specialists of scientific, industrial and public organizations of Russia, FRG, Bulgaria, Norway, Canada, Sweden, Netherlands, Kazakhstan, Armenia, Georgia, the Ukraine, Byeloruss, Moldova, and other countries.

The IIES is a non-governmental organization. IIES activity is executed over the territories of Russia and foreign countries under support of international and national public organizations, National Academies of Sciences, governmental institutions, committees and commissions, industrial enterprises, companies and organizations.

The IIES combines efforts and unites activities of scientists on forming a general theory and conception of technical facilities safety, on working out of methods and safety providing means for certain most potentially hazardous structures and manufactures, on implementation and usage of safety technologies, on enlightenment activity, as well as on forming a safety culture and spreading it in society.

The problems solved in the framework of IIES activity consist of the following main elements:

- fundamental scientific developments of accidents and disaster theory (physics, chemistry, disaster mechanics, principles of hard and functional defence, physical and mathematics modelling and monitoring, emergency diagnostics);
- prediction of catastrophic natural phenomena, and parameter definition of their impact on complex technical systems, on towns and population;
- international cooperation on population protection against accidents and disasters (warning, rescue, evacuation, life supply measures, etc.) and on their liquidation of their consequences;

The activity of the IIES is carried out on the following main trends:

- research accomplishment on theory and safety criteria of complex engineering systems;
- applied developments on projects of providing safety for complex engineering facilities;
- personnel training and information services on the problems of safety of complex technical systems.

The principal tasks of the Institute covered by the program of its work are as follows:

- transfer to novel design technological solutions to prevent large-area technical accidents and natural calamities;
- mitigation of accident and disaster consequences in cases when their prevention is impossible;
- execution of combined national and international measures on population protection, as well as on liquidation of accident and disaster consequences;
- development of a unified international conception, criteria and principles of ensuring engineering facilities' safety (for nuclear power facilities, aircraft and aerospace systems, chemical enterprises, transport systems, machinery and metallurgic enterprises, special equipment facilities, pipe lines, etc.);
- development of methods and systems of international warning about major accidents and disasters and coordinated actions in hazardous zones;
- development of principles, technologies and techniques of liquidation of the consequences of accidents and disasters at complex technical systems in emergency areas and in natural calamity zones;
- creation of main principles of emergency monitoring, rescue and emergency diagnostics in technological disaster zones and natural calamity areas; and,
- information exchange and collaboration in the field of methods and means of actual diagnostics of emergency situations and safety.

The IIES is open for the affiliation of other organizations and specialists in Russia and other countries as founding members and participants in its work, sharing the purposes and scope of its activities, and who are interested in realization of joint developments in the field of ensuring engineering safety of complex technical facilities.

COMPUTER-AIDED SAFETY SYSTEMS OF INDUSTRIAL HIGH ENERGY OBJECTS

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KEYWORDS

fire safety, industrial safety, computer-aided

ABSTRACT

The addressing of fire safety problems of large-scale industrial objects by means of Computer-Aided Fire Safety Systems (CAFSS) are considered in this paper.

Modern objects of fuel and energy, chemical industries are characterized: by high power consumption; by presence of large quantities of combustible and explosive substances used in technological processes; by advanced communications of submission systems of initial liquid and gasiform reagents, lubricants and coolants, the products of processing, and wastes of production; by advanced ventilation and pneumatic transport; and by complex control systems of energy, material and information flows. Such objects have advanced infrastructures, including a significant quantity of engineering buildings intended for storage, transportation, and processing of combustible liquids, gasiform fuels and materials, and firm materials. Examples of similar objects are nuclear and thermal power stations, chemical plants, machine-building factories, iron and steel industry enterprises, etc.

Failures at such enterprises are classified as "heavy." They are dangerous not only for staff of these enterprises, but sometimes for the whole region. Such failures are characterised by high material and social damage. According to research conducted by the Higher Engineering Fire Service Technical School (HEFSTS), the reason for heavy failures at the mentioned objects is fire or explosion.

Many tasks and functions characterising the problem of fire safety of these objects can be accomplished only upon the development of special Computer-Aided Fire Safety Systems (CAFSS). The principles of construction and functioning of CAFSS have been developed by the Special Electrical Engineering, Computer-Aided Systems and Communication Department of HEFSTS, jointly with other academic and trade scientific research institutes and design offices of Russia.

The CAFSS for these objects are intended to reduce the hazard of disastrous accidents both causing fires and caused by them. The tasks of fire prevention and rescue work of large-scale industrial objects are analysed within the bounds of the recomended conception. A functional structure of CAFSS with a list of the main subsystems forming a part of its composition has been proposed. According to the recommended conception, CAFSS should be designed as a single complex, organizing technical and software components, which has a multilevel hierarchical structure.

A great deal of attention in this conception is devoted to the problem of providing the object with fire safety while it is still in the design stage. The Computer-Aided Designing Fire Safety System (CADFSS) is a part of the CAFSS. The purposes of CADFSS are to work out constructive planning solutions to reduce the probability of fire breaking out and spreading. Among other purposes of CADFSS are the choice and combination of active and passive methods of fire protection, choosing and placing the systems of fire protection equipment, etc.

A data base of fire-prone outages of equipment elements must be created for storing and further processing in the framework of the Computer-Aided Fire Safety Informative System (CAFSIS). This data base can be processed by the method of probability analysis for defining the work to capacity of different equipment elements. Based on this analysis, recommendations can be formulated for a period of conducting preventive repairs, replacing equipment by new equipment, or changing its work regimen.

Reducing the hazard of disastrous accidents and decreasing their negative effect on environment and people is closely connected with the creating of systems simulating and forecasting fire-prone situations which may occur. These systems are a powerful tool for monitoring technological control objects by means of generating control commands which may correct a technological process or completely stop it in urgent situations. Consequently CAFSS should be either integrated into the Computer-Aided System of Control Technological Processes (CASCTP) or made as an independent system (Topolsky 1994). Both systems should be made on the same computer hardware components, with an organizing information-control interface.

An increase in functioning reliability of all levels of CAFSS is ensured by the complex integrating and duplicating of the most important items of information, and also by using different hardware and software decisions.

The quality evaluation of CAFSS application efficiency is shown by an essential increase in discovery and effective localization of fire-prone situations by means of automatic fire equipment and fire brigades. Consequently, the level of object fire safety increases. The application of computer-aided systems creates the prerequisites for the improvement of fire brigades and actions to organize industrial object personnel for fire-fighting.

The possibility of acceptance of well–founded solutions to liquidate critical situations is ensured by the automatic analysis of information received from fire alarm sensors and from an object's technological equipment, with the consideration of computer–aided forecasting. The continuous control of automatic fire equipment's capacity for work makes it possible to increase the reliability of its work, and to reduce the equipment stoppage time connected with the search for equipment outages. The CAFSS makes it possible to realize continuous control for carrying out of the object's fire safety measures.

The social efficiency constituent of CAFSS quality evaluation includes the following socially significant components:

- first, personnel's confidence that their life and health are reliably protected from the influence of fire dangerous factors;
- second, an essential reduction of personnel fluctuation and population migration from regions where large–scale industrial objects are placed;
- third, an increase in the efficiency of work productivity and social productivity by means of the combined action of the first two factors; and,
- fourth, an essential reduction of the probability of fire sacrifices and injuries to people during the action of fire dangerous factors.

The recommended approach was used for working out fire safety systems for the new generation of nuclear power plants, industrial enterprises with high power available per worker, and other objects.

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INTEGRATED COMPUTER–AIDED SAFETY SYSTEMS

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KEYWORDS

integrated safety, hierarchical systems, mathematical simulation

ABSTRACT

Integrated Computer–Aided Safety Systems (ICASS) have been developed as a means of ensuring industrial safety. This paper discusses the structure and characteristics of ICASS, and the methodology of constructing and simulating a hierarchical system.

Statistics of large failures in the world show that steady growth in the number of these failures has taken place recently. This tendency is caused by many factors, the main ones of which are: aging of equipment; growth in the number of high power-consuming enterprises; a large risk of heavy failures and extraordinary situations; slow introduction of new information, communication, and organizational technologies; a low level of automation of safety assurance; and backwardness of the normative base.

The latest results, as well as the experience of creating and introducing Computer-Aided Safety and Life-Support Systems, show that the problem of ensuring safety can be solved only on the basis of prevention and liquidation of all threats. Threats against such objects are complex, multi–factor phenomena, which have a discrete–continuous nature and different forms. These threats are characterized by differences in development, as well as an ability to be displayed in various combinations at extraordinary situations. The most dangerous threats are extraordinary situations (fires, failures, accidents, natural calamities, earthquakes, etc.) and threats to functioning of an object (disorganization of work, management, non-authorized access to information, etc.).

The methodological base to solve this problem is the system approach. Its technical realization is the Integrated Computer-Aided Safety System (ICASS).

ICASS consists of the following subsystems: Fire Safety System; Ecological Safety System; Safety System of Extraordinary Situations; Security System; etc.

The purpose of designing ICASS is to create an effectively functioning mechanism that ensures the necessary level of integrated safety (IS) for an object at all stages of its functioning.

Use of the system approach when creating ICASS should ensure complex realization of the following directions: passive methods, ways, and means of protection; automation of the main processes of IS assurance; operative and operative–technical services' activity; and, effective completion of organizing–administrative measures.

ICASSs are intended to reveal and prevent threats, and to liquidate their consequences. ICASS' main tasks are:

- maintenance of the necessary level of safety at all stages of the object's life cycle by revealing, preventing, localizing, and suppressing threats and liquidating their consequences;
- support of effective functioning of hardware to ensure the required level of safety;
- maintenance of effective management of operative and operative–technical services and divisions;
- ensuring of interaction with overhead structures;
- forecasting of extraordinary situations;
- archiving of data about functioning of the system in its attendant regime and during the action of threats;
- providing information and decision–making support to operators and chiefs of operative and operative–technical services, and to the head of the object, by the use of simulation, forecasts of operative conditions, data bases, knowledge, and recommendations; and,
- training of operators and chiefs of services.

ICASSs have the following characteristic features:

- ICASSs are part of Computer–Aided Safety and Life–Support Systems. They are integrated in a uniform complex with safety systems (fire, security, ecological, etc.), and they interact with life–support systems (electricity supply, heating, water supply, etc.).
- ICASS works at all stages of an object's functioning life cycle (designing, construction, putting into operation, operation, modernization, and scheduled liquidation).
- ICASS operates during the whole time of occurrence, development, localization, and liquidation of a danger's consequences.
- The system provides disposed in–depth, multi–stage protection of an object and staff from dangerous factors.
- ICASS has a distributed, multi–level structure, adapted for a particular object and technological process.
- Modules of the system can work both independently and in the structure of other systems. They are

constructed on a uniform programming, technical, and information base whenever possible.

The main principles of the system approach used in ICASS are (Gubanov *et al.* 1988):

- the principle of final purpose (the absolute priority of final, global, purpose);
- the principle of unity (consideration of the system as both a whole and a set of its parts);
- the principle of connectedness (consideration of any part of the system together with its connections to the others);
- the principle of block structure;
- the principle of ability to work independently and in the structure of the system;
- the principle of hierarchy;
- the principle of functioning (joint consideration of structure and functions when the priority of functions is considered);
- the principle of development (keeping records of changes in the system, its development, expansion, replacement of parts, and accumulation of information); and,
- the principle of distribution (combination of centralization and decentralization of management).

The organizational structure of ICASS includes: a command system; a multi–level system of control, containing relatively independent bodies of management at each level; and a system of coordination. One of the main properties of ICASS is its hierarchical structure. It is also impossible to describe on a "physical level" either the processes which take place at extraordinary situations, or the connections between parts of the system. The hierarchical structure of the system is one of its basic attributes, determining the directions of its development as a difficult teleological system, with mutually connected functional elements (bodies of management, subsystems, etc.) distributed by subordinate levels.

The problem of construction of a difficult hierarchical system is largely related to the problem of mathematical simulation of processes proceeding at the objects, and of logical connections between separate interconnected elements of the object.

Matters of decentralization and coordination of decision making are the basis of the methodology of hierarchical models' construction (Chernyishov and Gadzhiev 1983). Hierarchical complexes of management are expedient for solving large dimension tasks, which have a lot of management variables and are intended for large systems. The model of such a system should ensure the replacement of main large dimension tasks by a set of relatively independent lower dimension tasks and coordinate solving them in a uniform global decision for the initial model.

The main features of the mathematical simulation of ICASS' hierarchical structure in the described approach are:

- representation of the command system as a task decisive global model in the sphere of coordination of management bodies' local tasks;
- constructive decentralization of models by introduction of independent and specialized management bodies;
- theoretical–playing representation of interrelations of management bodies;
- introduction of two kinds of management—functional and by levels;
- allocation in hierarchical models of a special system provided by unformalized and automatic coordination;
- generality of ways of solving the problem, based on the principles of coordination; and,
- realization of synthesizing the models and analyzing their conditions.

Another problem of ICASS model creation—a problem stipulated by the impossibility of representing processes, functions, and connections by determined physical models—is solved by computer on the basis of the principle of self–organizing (Ivakhnenko and Yurachkovsky 1987). According to this principle, teleological testing by several criteria is realized of many models of various complexity, and the model with the optimum structure is found.

A possibility of applying this method is caused by the impossibility of creating a "physical model," in which variables and the field of simulation of all elements and connections are defined by a person on the basis of knowledge about the object. The "non-physical model" then used has the following basic features:

- absence of a full information basis;
- partial reflection of the object's mechanism of functioning;
- connection between instant and average values of factors during various intervals of time;
- approximation of a "basic function" by a rather complex function; and,
- absence of a plain, formalized interpretation of processes and connections inside the object.

Thus, simulation of an object's ICASS should largely rely on a methodology based on the use of mathematical models of complex hierarchical systems, and on the principle of self–organizing of the models.

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TIEMEC '95

System Applications

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OPTIMIZATION OF ROUTES OF EMERGENCY SERVICES' VEHICLES TO THE PLACES OF CALLS

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KEYWORDS

graph theory, optimization, vehicle routing

ABSTRACT

An algorithm is described for optimizing the routes of emergency service vehicles between their initial locations and the places of calls. The algorithm uses graph theory to minimize the time or distance traveled.

To reduce material and human losses at extraordinary situations, the task of minimizing the time between a fire, explosion, accident etc., reception of a message in the means and forces' management centre, and arrival of response vehicles at the place of call is critical. One of the ways of accomplishing this is to choose optimum routes for the vehicles.

To solve this problem we propose to present the map of a district as a suspended graph G, the tops of which are crossroads (V), and arches of which are the streets joining adjacent crossroads. The value of graph's arches can be the distance between crossroads, time of traveling between them, etc. Moreover, the following features of the graph should be taken into account:

- for taking into account one–way roads, tops of the graph can be connected by oriented ribs;
- the speed of traveling along a two-way road can differ depending on the direction;
- if traveling time is chosen as a value of the graph's arches and ribs, it can vary depending on season and time of the day;
- in general, graph G is not flat (such crossroads as overpasses, bridges, tunnels, etc., are possible).

To solve the task of optimization it is necessary to give a mathematical description of the graph. It can be described by incident and contiguity matrices, as well as in list form. We propose use of the latter way as the most saving of operating memory of the computer.

Raising the task of optimization is as follows: let a graph of the map of a district $G = (V, A)$ be given, where V is the set of tops and A is the set of ribs. Let each rib a_i have weigh g_i. It is necessary to find the route from top V_l, corresponding to the location of emergency services, to any top V_k, such that $S(l,k) = SUM(g_i)$ is minimized.

The task can be solved by sorting out all possible routes; however, there are too many of them on the map of a real city. That's why the task should be solved by the method of dynamic programming (or step–by–step optimization).

An algorithm to solve the task is made on the basis of the Diikstra approach, in view of the features of graph G. This approach permits us to find the route of minimum length between any two tops of the graph, however, it is not practically applicable for a real city in a real scale of time in spite of minimizing calculations by using dynamic programming.

In this regard, an algorithm enabling us to solve the task in two stages is proffered. In the first stage, calculation of the shortest route's trees from the locations of emergency services' vehicles to all the tops of the graph is made after filling of the data base containing the description of the map of the city and locations of emergency services' vehicles. Solving of this problem requires the heaviest temporary costs and is performed beforehand. Results are recorded in a matrix of shortest routes' trees of graph G. The estimated accounts show that, using the "assembler" programming language on the computer "Besta" to solve this problem for Moscow, which has about 100,000 crossroads, it requires about two months.

The second stage consists of restoration of the optimum route from the vehicles' locations to any top of the graph. It is done when a request for dispatch is received and requires very little time, because it just consists of consecutive "reading" of the route along the tops of the trees already built in the first stage.

Thus, use of the proffered algorithm permits us automatically to define the nearest location (by time or by distance) of emergency services' vehicles and find the optimum route in the admissible time.

If it is necessary to take into account the changes of weights of the graph by the time of the day, by seasons, or by periodic changes of city traffic (raised bridges, etc.), it is possible to calculate several variants of matrices of the shortest routes' trees of graph g and use the variant that satisfies the present situation at each particular moment.

The proffered algorithm was realized as a program in the computer language, BASIC. The program allows us to calculate a graph of 100 tops, each of which has four ribs on average. The number of locations of emergency services' vehicles is not limited. The time of calculation of this graph is 24 minutes. After that, the route to any top is built without delay and is determined by the speed of display units working.

FLORINUS
AN EMERGENCY MANAGEMENT, INFORMATION AND COMMUNICATION SYSTEM FOR FIRE BRIGADES, POLICE FORCES AND CIVIL PROTECTION

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ABSTRACT

The PIETZSCH FLORINUS system is based on developments of Control and Information Systems for German task forces, who used similar systems, e.g. during their UN mission in Somalia.

FLORINUS supports the following actions of platoon and group leaders of fire brigades and of civil protection, police and rescue services:

- Determination of own position in the operational area
- Indication of the positions of the other forces in operation
- Working out of operation plans with graphic support and standardised symbols
- Transmission of mission plans and observations
- Indication of weather data, traffic situation etc. through a link to other data bases
- Integration of data of external sensors like wind direction and speed from weather stations, or lines of sight of observation stations for triangulation

FLORINUS is based on standard computer hardware and standard computer operating systems for the stationary office systems and the mobile systems as well. The man-machine interface is based on an electronic map where actions are initiated using function keys or soft keys and the creation of messages is graphically supported and menue driven.

INTRODUCTION

In the case of all disasters which appeared up to now, but also in the case of many damages lying under the threshold of what is defined as „catastrophe“, the past and also the latest disasters have shown that exploration of the actual situation and communication between the various task forces and organisations need to be improved in a large scale in order to mitigate the disaster consequences. This fact will be confirmed by all responsible authorities and organisations.

Especially during the initial phase of a disaster it is very difficult for the responsible persons in every level to obtain an exact image of the actual situation. And therefore it is hardly possible to make the right decisions.

At the moment there are many manufacturers of communication and information systems for stationary headquarters. But for the use in mobile headquarters and at the level of the operational forces the communication and information exchange still is based on verbal messages, transmitted by radios. There is a clear lack of means supporting an advanced information management in this application field.

Due to this fact inaccuracies, misunderstandings and loss of time arise at analysing the situation and for consequence at giving instructions and making decisions. In addition there are the imaginable difficulties in communication with the operation center. May be the communication by radio is disturbed or the communication via a line is interrupted. The more one has to considerate inarticulate spelling and difficulties in wording of some people.

APPLICATION AREAS

The application area of the FLORINUS System is the protection from dangers in the widest sense. These are, above all, disasters, but also events lying under the threshold of what is defined as "catastrophe", especially in the following areas:

- forest fires
- fires in major industrial plants
- accidents arising during transport of dangerous materials and goods
- disasters in residential neighbourhoods (e.g. aircraft crashs or bomb explosion)
- natural catastrophes arising from flood, storms or similar events

FLORINUS can be used in all levels of public authorities who are responsible for protection of affected people and the protection from the respective dangers. These are, above all, the Communities and Districts. But also the Governments of Districts, Ministries of the Federal States and in some cases also the Government of the Federal Republic of Germany do bear responsibility.

The mobile systems can be used by civil protection, emergency services, police, fire brigades and forestry as well.

SYSTEM DESCRIPTION

There are two different systems which have basically the same functionality.

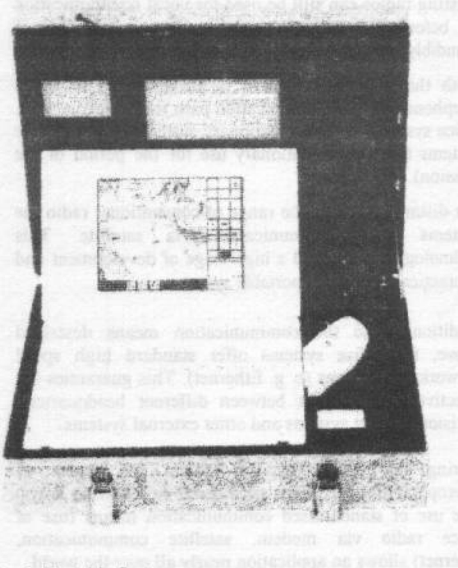

Fig. 1: Portable System

The portable system for platoon and group leaders is shown in Fig. 1. Central component of the system is a notebook computer as it is available of the shelf, which has been integrated in a shock and water resistant metal case in order to be protected from environmental influences. On the notebook´s display a digital map of the mission area is shown. The digital map is based on maps from CD-Roms in standard format from map agencies or on paper maps, which have been scanned into the notebook in various scales. On the map the own position, represented by an icon is shown. The system obtains the necessary information for this purpose from the integrated Global Positioning System (GPS).

The stationary (or office) system (Fig. 2) with a larger high resolution monitor for operation centers and public authorities is based on a workstation. Its primary use on this level is for presentation of information from task forces in operation (observations, messages), for mission planning and for information exchange and communication between authorities. With the higher performance of the workstation big data bases can also be administrated.

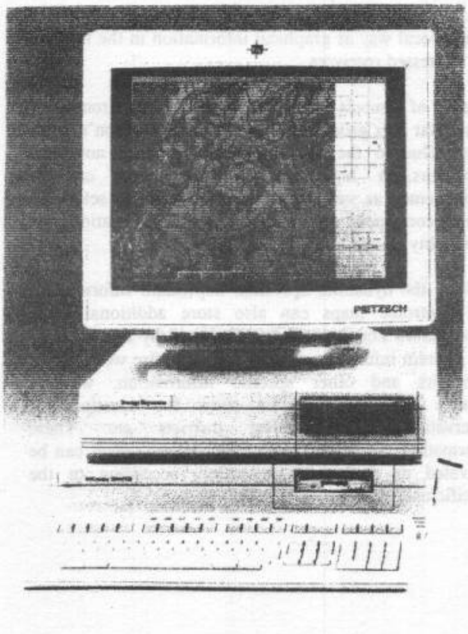

Fig. 2: Office System

Basic Functionality

Most of the features are based on digital electronic maps, which are stored on the mass storage device of each individual system. It is presented to the user by a high resolution colour display. The user can manipulate the presentation of the map in many ways to optimise it for his individual needs. He can vary the scale, he can select and move the section he is interested in and he can choose the degree of information in several levels (see Fig. 3).

The information exchange with other users takes place on the base of graphical information and symbols, which are entered to the map. These informations can be easily sent to any user via various communication means (see below). The information appears unmistakably on the map of the addressed user or user group at the correct position (world co-ordinates) and with the desired appearance.

By this means police, firemen, foresters or other rescue services can send status reports, observations and requests by using their portable systems. On the other side headquarters can collect the information of all the officers in charge in the field, plan the actions to be taken and send the correspondent commands and informations to the engaged services. These data appear in an unequivocal way as graphical information in the maps of the addressed receivers.

The set of symbols applied by different user groups and by similar user groups in different countries won't be the same. Due to the big storage capacity of nowadays computers, a high amount of symbols can be implemented as subsets, so that the user can select the subset corresponding to his field of application and nationality.

Besides the dynamic, operation dependant informations the electronic maps can also store additional static information. For instance systems used by fire brigades can contain information about hydrants, fire wells, water reservoirs and other specific information, whereas systems used by foresters show the locations of observation towers, forest districts etc. These informations are stored in different layers which can be activated or deactivated separately according to the specific user needs.

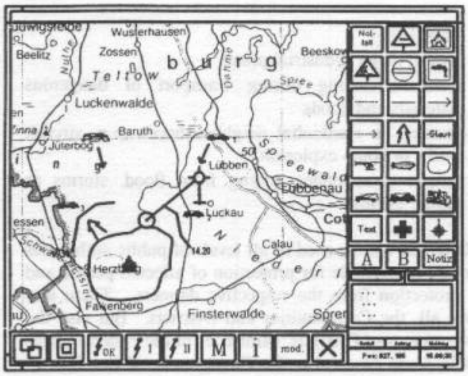

Fig. 3: Electronic map with symbology

Communication Concept

There are various possibilities for the communication between the users. The portable systems contain modems which allow the connection to standard voice radios for information transfer. The existing radios can be used for this purpose without any need to provide additional radios exclusively for the information system. The existing radios can still be used for vocal communication as before, because the data exchange takes place inaudibly in speech pauses.

With the built in modem it is also possible to use a telephone line as communication path for stationary (i. e. office systems) or quasi stationary systems (i. e. portable systems that are in stationary use for the period of the mission).

For distances outside the range of conventional radio the systems offer communication via satellite. This technology has reached a high stage of development and is practicable even for portable systems.

Additionally to the communication means described above, the office systems offer standard high speed network connections (e. g. Ethernet). This guaranties the effective data transfer between different headquarters, decision support systems and other external systems.

During the design of the system the aspect of interoperability has been considered in different ways. The use of standardised communication means (use of voice radio via modem, satellite communication, ethernet) allows an application nearly all over the world.

As the information exchange is based on symbology and therefore mainly language independent, the system can be used cross border. Only very few messages like system status information, help information or some messages appear as text messages. These messages can be presented in English or, if necessary, can be stored in different languages in the computer and the user can select his mother language.

Interfaces

The systems offer different interfaces for internal and external sensors. The portable systems contain a complete satellite based positioning system (GPS, global positioning system) and a built-in electronic compass. So every user knows exactly his own position and heading. These two informations are graphically presented by an icon on the electronic map. They are currently updated and automatically broadcasted. So the other users, especially the headquarters, are always aware of the actual position of all forces in the field.

There can be different external sensors that provide the systems with information. They can be distributed over a larger area and can be connected to the system by one of the above mentioned communication means. For example, universal weather sensors can provide information about temperature, wind direction and strength etc. as input to the office system.
With the network capability of the office system it is possible to interface with other systems, e. g. expert systems, data bases and conventional headquarters systems.

Ergonomic Aspects

A very important aspect for the efficiency and acceptance of the presented system is the implementation of the man machine interface. As most of the users (e. g. foresters, firemen) are not used to work with computers, this interface must be easy to learn and easy to use, it must not frighten even an unpractised user. It has to be optimally adapted to the specific needs of the different user groups.

This requirement is realised by different approaches. First the information representation is performed by graphical means in a way the user is accustomed to. E. g. the electronic map has an appearance very similar to the conventional paper map - but with more functionality - and the symbology used for information presentation is also well known to the user. The second aspect is the handling of user inputs. It is done by pointing to symbols, which represent the desired actions. For office systems the pointing can be performed with a computer mouse, for portable systems other means such as trackballs and touch screens are more suitable. The last aspect we want to mention is the logical structure of the interface software, which allows the user to perform the desired action with few, transparent steps.

SUMMARY

The systems, especially the hardware, as described above are in use of the German UN task forces and have been used in Somalia.

Currently we are making available this technology for other users and applications under the name FLORINUS and have recently introduced the system to fire brigades, police and public authorities.

The acceptance was so high and the response so good that we started to implement fire brigade and other civil protection services specific symbology and message sets, so that a demonstrator system especially for use by fire brigades is existing.

The FLORINUS system will not replace but add on existing standard emergency control stations. Its emphasis is on the control of mobile forces in major accidents and the actual information of the emergency manager.

As the messages are mainly represented by graphical symbols, no language barrier occurs though that the system can easily be used cross border.

If the European activities to field standard radios will be successful, also the communication via radio will be possible through the European wide user community.

CARBON DIOXIDE DISPERSAL AND ASPHYXIATION: SHARING COMPUTER SCIENCE WITH CULTURE, MYTHS AND LEGENDS.

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KEYWORDS: volcanic gases, carbone dioxide, asphyxiation, heavy gas dipersal modeling, myths and legends.

IMPACT OF THE VOLCANOES ON HUMAN ACTIVITIES

In spite of modern technology, it is still difficult to predict the beginning, the end, and the magnitude of a volcanic eruption. Ancient civilizations managed volcanic catastrophes using myths and legends. Concerning phenomena leaving no geological prints such as toxic gases, modern volcanology refers to phenomena having a recurrence time of centuries to millenia or more as evidenced by written texts a few centuries old. Considering the myths and legends around Lake Nyos (Cameroon) where cultural transmission is essentialy oral, and comparing testimonies of the August 1986 event with the data obtained by scientists, it has been possible to reconstruct the catastroph history. Scientific observations are used to define the boundaries of a computer modeling describing the toxic gas propagation. Testimonies and modern medical knowledge are confronted. This experience made it possible to reinterprete the plague killing the inhabitants of Arequipa (Peru) in 1718 as probably due to the emanation of toxic gases from Mt. El Misti volcano.

IMPACT OF THE VOLCANOES ON HUMAN ACTIVITIES.

The volcanic activity affects the atmosphere and ocean chemistry but often volcanoes destroy human goods in explosions, flows, avalanches, etc,. Since the middle of the last century, modern technologies has induced a tremendous expansion of the population . Major modern population centers were settled in complete ignorance of volcanic risks. Big cities like Naples, Mexico City, and Tokyo are in a situation where a small ash fall of few cm would dramatically affect the economy. Volcanic eruptions represent a significant hazard for civil air transport. Numerous encounters of aircraft flying through volcanic plumes have been reported in the past 15 years. These incidents were sometimes serious (US Geologicaln Survey 1991).

Up to now the major volcanic catastrophes have happened in deserts, national parks or sparsely populated areas affecting a few 100,000 people. But in January 1995, Mt. Popocateptl (Mexico), Mt Merapi (Java, Indonesia), and Mt Niragongo (Rwanda) threatened millions of people (Volcano Listserv 1995; Smithonian Institution 1995).

THE LIMIT OF VOLCANIC ACTIVITY FORCASTING

Using the up-to-date volcano survey equipement it is easy to detect data suggesting impending eruption. Detection has sometimes failed because rising magma suddenly stopped, soil inflation reversed, or a dramatic increase in gas temperature did not correlate with the volcano behavior. Prediction of the initial stage of an eruption is still difficult; but, it is impossible today to predict a volcano's magnitude and duration. (Tazieff and Sabroux 1983; McBirney 1983,Tazieff 1988;Tazieff and Derruau 1990, Shimozuru 1991). A dozen volcanologists were killed in the last decade in situations they could not completely predict.

In the last decade computer developpement made possible to simulate volcanic activity, lava flow developpements, gas trajectories… These models to be valid need to be tested on the real situations. Volcanology is only few centuries old and the informations are mainly transmitted by written traditions. Geological records are not enough to reconstruct past eruptions: Huge gas explosions leave very tiny geological prints.

Recently we have been involved in carbone dioxide outbursts dividing the scientific community and pointing out the necessity to share modern science and old traditions.

LAC NYOS (CAMEROON)

The Scientific debate:

The catastrophic event at Lake Nyos (Cameroun) has resulted in a major scientific debate. On August 31 1986, more than 1800 people, 6000 cattle, birds and wild animals were asphyxiated by a toxic gas. Local authorities ask for help and scientists from the major developed countries were sent by their governements in order to determine the origin of the catastrophe, diagnose the possibility of a new event, and study the possibility of predicting and preventing such new events.(Tazieff *et al.* 1986; Le Guern and Sigvaldason 1989; Le Guern and Sigvaldason 1991)

Similar catastrophes occured in Indonesia in February 1979, and Lake Monoun (Cameroon) in August 1984.(Le Guern et al. 1982; Sigurdson et al. 1987).

The entire scientific community agreed that the catastrophe was due to carbon dioxide from a magmatic origin. Two scenarios have been used to describe the catastrophe:

(1) the volcanic origin scenario : a gas jet spitted across the lake water; or

(2) the limnic origin scenario: gases were stored in the lake water and an internal or external phenomena triggered the degassing.

In the volcanic scenario prevention of degassing is impossible. Any volcanic area can present this danger in, or outside lakes; prediction will proceed with usual methods. (Tazieff 1991)

In the limnic scenario both prediction and prevention are possible: The only dangerous area being located around lakes containing dissolved gases, prevention can be obtained by pumping the deep waters to the surface where they will naturally degassed.

This scenario has been presented as a new geological hazard.(Sigvaldason 1991)

SCIENTIFIC OBSERVATION AND COMPUTER SIMULATIONS.

Sent by the french government we arrived on the lake shore 4 days after the occurence and observed all the facts that could help to reconstruct the event:

Figure 1:

- bodies were found 23 km from the lake,
- dead animals were found on southern hills 120m above the lake surface
- a cliff on the lake shore had been washed and stipped from its all cover up to 80m elevation
- in situ measurements pointed out a huge CO2 flowrate from the ground all around the lake
- surface lake water were oxidized but deep waters were clear and undisturbed
- mechanical effects of strong wind were observed in valleys down slopes 3 km from the lake (Tazieff et al. 1986).

Taking into account the percentage of surviving people place by place in the all area it has been possible to draw a hazard map (Le Guern et al. 1992).

Reviewing what is mainly known about carbon dioxide intoxication it has been possible to evaluate the atmospheric carbone dioxide concentration and draw a map of carbone dioxide isoconcentrations deduced from the survival rate for human beings and dose effects relations (Faivre-Pierret and Le Guern 1983; Stupfel and Le Guern 1989)

A modelling has been carried out by using a three-dimensional thermohydraulic code (TRIO) . This code is qualified for modelling the dispersal of heavy gases and has been developed by the "Commissariat à l' Energie Atomique France" (Magnaud et al. 1987; C.E.A. et al. 1989)

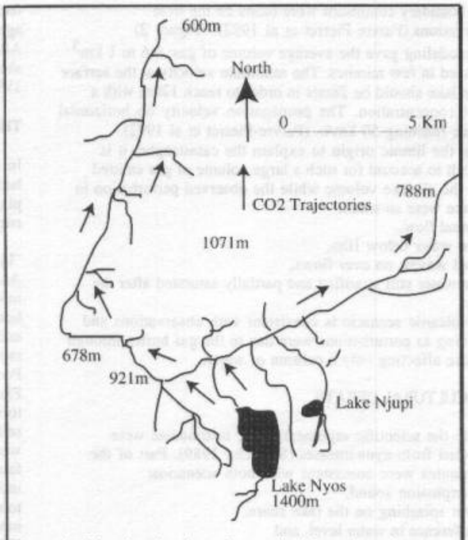
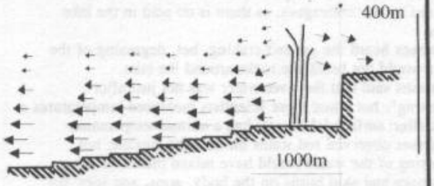


Figure 1: Map showing the carbone dioxide trajectories (After Tazieff et al. 1986)



Arrows representing the calculated speed vectors: maximum calculated velocity: 36,3m/s

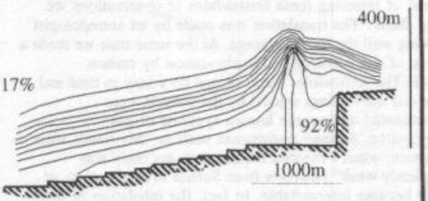


Figure 2: Lake Nyos 1986: Graphic representing the results of modeling as velocity vectors and lines of gas isoconcentration along a trajectory from Lake Nyos down to the valley. They have been validate by the field observations.

The boundary conditions were based on the field observations.(Faivre-Pierret et al 1992). (Figure 2)

The modeling gave the average volume of gas: 0.6 to 1 km^3 degassed in few minutes. The minimum velocity at the surface of the lake should be 28m/s in order to reach 120m with a lethal concentration. The propagation velocity on horizontal surface reaching 50 km/h. (Faivre-Pierret et al 1992).

Using the limnic origin to explain the catastrophe, it is difficult to account for such a large volume of gas emitted from the all lake volume while the observed perturbation in the lake were so small:

- no mud flow,
- clear water below 10m,
- small waves, no over flows,
- lake water still stratified and partially saturated after the event.

The volcanic scenario is consistent with observations and modeling as perturbations were due to the gas hurles through the lake affecting only a column of water.

THE CULTURAL DEBATE

Beside the scientific argumentation , testimonies were collected from eyewitnesses.(Shanklin 1989). Part of the testimonies were consistent with both scenarios:

- an explosion sound,
- water splashing on the lake shore,
- a difference in water level, and
- the existence of white clouds .

Other testimonies were rejected by our colleagues as they were made by people having a different culture, ignoring the basic geology and expressing their observations in a language mixing superstitions and observed facts.

Witnesses said they smelled acid. This observation were rejected by our colleagues, as there is no acid in the lake water.

Witnesses heard the ground craking, but, degassing of the water would not break the rocks around the lake.

Witnesses said that the river water was hot just after degassing": but when these scientists measured temperatures a week after: surface lake water had a normal temperature.

Witnesses observed red stains on the lake surface; but, degassing of the water would have mixed the entire lake.

Witnesses had skin burns on the body, arms, and legs; but, the lake water was not warm or acidic.

Interpreting testimonies:

Instead of rejecting these testimonies or observations we tested them . The translation was made by an antropologist knowing well the local language. At the same time we made a review of the pathology of asphyxiation by carbon dioxide.The testimonies were located on a map in time and place and the feelings related by the witness were reexaminated against the known syptoms of gas asphyxiation. Strange testimonies such as "My hands were all frozen; when I reached the hospital, my body was completely weak" (survivor from Subum in Le Guern *et al* 1992) became interpretable. In fact, the inhalation of high concentration of carbon dioxide is known to provoke a shift of plasma from the periphery to the core of the boby (Arends *et al.* 1952; Billings and Brown 1955). The effects and feelings are very similar to what occurs during a cold agression (Stupfel and Le Guern 1992).

After completing this work it was remarkable that we were able to reconstruct the event in space ad time (LeGuern *et al.* 1991).

THE PLAGUE OF AREQUIPA (PERU) IN 1718.

In 1991 when studying the eruption of Sabancaya (Peru) we had the opportunity to collect a text describing the general plague affecting in Peru the City of Arequipa in 1718 the english translation is as follows: (Huaman 1991)

"In July August and September 1718 people suffered in Arequipa from a very hot and fetid southern wind giving to the most aware the fear that something fatal happened. The heaviness and tightness of the wind spoiled the atmosphere, and short time after, the plague contagion disseminate rapidely, and at the end of September it spread all over. People in the city and suburbs were affected.

Places and streets stayed deserted, very few people being able to walk around. Food was lacking as no people were able to sell or buy wares. In this situation basic supplies and welfare were nonexistant. The illness consisted of a great dullness, fainting, feebleness in all the senses, a pain feeling indistinctly in the whole body, general lassitude, deafness, total prostation, fever, and lack of appetite with blood in mouth and nose .

"The people already sick, especially those suffering from chest ailments died quickly, as well as those using medications prescribed by doctors.

The strongest people were wearing a lot of cloth and sweated. They felt extremely heavy and ill, having bodies feeling very weak, being dim sighted and looking sad and drawn. A long time was necessary to dissipate the troubles of the disease.

"The major part of the city became deserted. There were so many dead that churches and cemeteries were not sufficient and it was decided to transport them on carts in the contryside where pauper's graves were especially dug. In the city the major part of the houses remained opened some were completely bewildered but nobody took care of the oufits and furnitures they contained."

PLAGUE OR CARBONE DIOXIDE ASPHYXIATION ?

When they diagnosed this catastrophe people ignored the intoxication by carbone dioxide. Plague was well known to have already killed millions of people in Europe. But today when we compare the testimonies collected in Arequipa in 1718 with those collected around Lake Nyos in 1986 they are similar.

In Arequipa people felt "a very hot fetid southern wind": Around Lake Nyos survivors said that they "heard something like a breeze or a wind like before the rain" and felt a heat impression.

In Arequipa able-bodied people wearing a lot of clothing were sweating

Inhalation of 6% carbone dioxide provoque an increase in the sweating rate.

In both places people were prostrated, "unable to walk even to talk..."

STRANGE IDIAN LEGENDS:

Other similar cases are reported in indian legends around Aconcagua in the Andes were a "bad wind" "The Puna" blows down the montain and legend says is produced by stones or vegetation . While studies on the role played by the respiratory sensation of low or high landers during high altitude hypoxia adaptation were carried out at base or altitude camp of the Aconcagua mountain (Plaza des mulas 4800m or Nido del Condor 5400 m), physiologists observed that altitude acclimatization did not present the classical or regular pattern as in other high altitude hypoxic situations (Andean or Himalayan ranges). Especially in area where CO_2 escapes from the ground (Noël-Jorand 1991personnal communication ; Noël-Jorand and Brunet 1994 A and B).

RISK MANAGEMENT FROM MYTHS AND LEGENDS :

Geologist are not usually aware from carbon dioxide; as usually emitted at great velocity and high temperature it mixes with the air and never reaches dangerous concentrations. But myths and legends contain strange stories in many places around volcanoes. When looking aerial photographs of Cameroon we can see that people settled around lakes since the last decade, when the unique voice of tradition has been replaced by multimedia and the multiple opinion of scientists.

KEEPING WITH ANCIENT CULTURES

We are trying to reconstruct natural phenomena having a reccurence of centuries or millenium on the basis of written documents. A huge amount of observations are conveyed by oral traditions in a language always including myths, legends and superstitions. We had with the Nyos case a good opportunity to correlate testimonies in local culture with scientific observations, measurements and knowledge. Modern developpement is uniformitizing cultures and it is urgent to collect these oral traditions before they dissapear . Degassing of toxic volcanic gases leave no readeable geological records; oral traditions can help to locate today's affected areas.

On Lake Nyos we were able to validate a model calculating the flow of carbon dioxide. It would be possible to simulate such a situatioon by calculating in other topographies.

THE COMMUNICATION PROBLEM

Leading volcanologists are proceeding to theoretical studies publised in specialized journals. They belong to the geology, chemistry, and physics communities. But, their opinions are now used by public authorities. Very few scientists are taking into account the social and legal problems induced by the transfer of their results to public officials, industries, and public services. Very often their statements are distorted or sensationalized by the media. In addition, there is no universal survey system, each volcano having its own specific behavior. Even when using the complete up-to-date set of geophysical, geochemical, and geological equipment, when computing simulations and models, the diagnosis will always be based on personal experience. This subjectivity sometimes induces conflicting opinions, especially when scientists sometimes try to seize the opportunity to highlight their activity and obtain more funds (McBirney 1983; Tazieff and Sabroux 1983)

In August 1994 Niragongo volcanic activity threaten one million refugees on its flanks. Experts from Zaïre, USA, Japan and France, claimed in October 1994 for cooperative studies and ask for an international meeting in Goma to plan monitoring efforts. (Goma Declaration). At Christmas time 1994 the head of the international humanitarian association "Médecin du Monde" Asked Dr H. Tazieff, President of the "Conseil Superieur d' Evaluation des Risques Volcaniques" to complete the international expertise wich described the situation in its volcanological aspect. Tazieff evaluates "the number of people that could be victims of the volcanoe and the number of refugees who should be badly exposed to death and serious diseases in case of a large scale transfer. (Tazieff 1995)

THE CULTURAL PROBLEM

When sharing our knowledge in the frame of scientific publications or international congresses we are using the same language and the same rules in the same culture. But when we are involved in the projection of our expertise in society, the conclusions we deliver to authorities can be completely different from one expert to another. Europeans, Asians, Africans, or Americans keep with their culture; the scheme they have to work in depends on the country in which they operate. In some the human life has no value; in others they cannot accept a death. This is a dimension of expertise that has not been usually taken into account.

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APPLICATION OF AN INTERNATIONAL DATA BASE FOR ANALYZING EARTHQUAKE STATISTICS

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KEYWORDS: earthquakes, international, data base, statistics, emergencies

ABSTRACT

This paper demonstrates some applications of an international data base for significant earthquakes. The prime focus is for determining statistics about earthquakes on an international level. Apparent trends which indicate some elements of periodicity in earthquakes are demonstrated. The value and limitations of the data base are also discussed.

INTRODUCTION

The National Geophysical Data Center (NGDC) has an impressive data base of earthquakes available at a nominal cost. The version discussed below was the most recent version at the time this paper was written (Dunbar 1992).

In this paper, the purpose of using this data base is to search for trends concerning earthquakes. This work is ongoing, and an update will be provided at the conference.

The version discussed below has data from 2150 B.C. to 1995 A.D., and has the most recent data available at the time this paper was written.

The data base is available in a printed form as well as in ASCII format on disk. The printed copy only provides information up to 1992, since it has not been updated in print, unlike the ASCII data, which is constantly being updated.

As point out on page 5 of (Dunbar 1992), it is misleading to compare data prior to 1962 to that after 1961, because of the number of recording sites and the type of equipment used prior to 1962. Also, to avoid comparing full years of data to that in 1995, which only has a small amount of data at this time, 1995 will not be used in the analyses that are discussed below. Thus, we will only consider data from 1962 to 1994 in this paper.

EARTHQUAKE INFORMATION CONTAINED IN THE DATA BASE

To be included in this data base, an earthquake must be "significant". NGDC defines "significant" as meeting at least one of the following four criteria:

1. Moderate damage (approximately US $1 million or more)

2. Ten or more deaths;

3. Magnitude 7.5 or greater;

4. Intensity X or greater (for events lacking magnitude data) on the Modified Mercali Intensity Scale of 1931; see pages 1-2 of (Dunbar 1992).

The data base includes such elements as: latitude and longitude of the earthquake epicenter; depth; year, month, day, hour, and minute of the quake; text description of the earthquake location; references to where the data was found in the literature; intensity of the quake; property damage in US dollars; and the number of people killed by the quake. Other useful items are also available in the data base.

SOME EXAMPLE APPLICATIONS AND ANALYSES

Figure 1 shows the number of earthquakes worldwide that meet this criteria as an annual average over three-year periods. In this figure, the 33 years covered have been divided into periods of 3 years. There are 11 such periods from 1962 to 1994. The number of earthquakes occurring in each period have been averaged, first on annual basis, and then as groups of three-year periods. The resulting number is an average number of earthquakes per year for each three year period.

There appears to be an increasing trend in the number of earthquakes per year. The number of earthquakes appears to have almost doubled over the 30 year period from 1962 through 1991. However, the last three years have had fewer earthquakes than one would expect had the trend from 1962 to 1991 continued. So another hypothesis would be that "significant" earthquakes are periodic in nature, and that we are now in a downward cycle. Observation of this apparent trend will continue.

It should be noted at this point that there are many duplicate records in this data base. Duplicate records exist because of different reports of the same earthquake. The duplicates are marked in the data base, and usually can also be determined by comparing dates and times for records which have locations (latitudes and longitudes) which are either identical or very close to one another. Where data conflict in the different "duplicate" reports, an average has been used in the analyses below.

It is also important to note that there are some incorrectly marked duplicate records in this data base. This data base has over 5,000 records (not just the portion from 1962 to 1994), and errors would seem inevitable in a data base of this size. The number of records concerning significant earthquakes that have occurred after 1961 exceeds 1,000 (including duplicate records).

These problems are mentioned in order to make the reader aware of some of the assumptions involved and problems encountered using this data. Special programs had to be written to recognize the duplicate records and to handle them in an appropriate manner. Duplicate records have occurred less frequently over the last 10 years, and hence, this may be an indication of more reliable earthquake reports.

Figure 2 displays the average intensity (using the Richter Scale) of significant earthquakes. Note that there appears to be a declining trend in the average magnitude of earthquakes from 1968 to 1991, but the last three years have shown a noticeable increase in the average intensity of significant earthquakes.

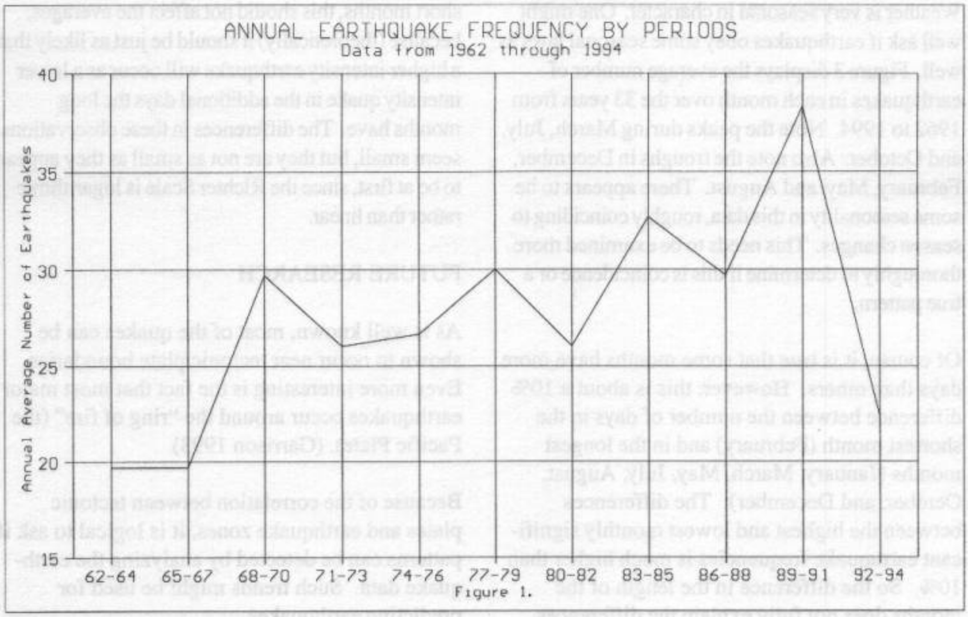

Figure 1.

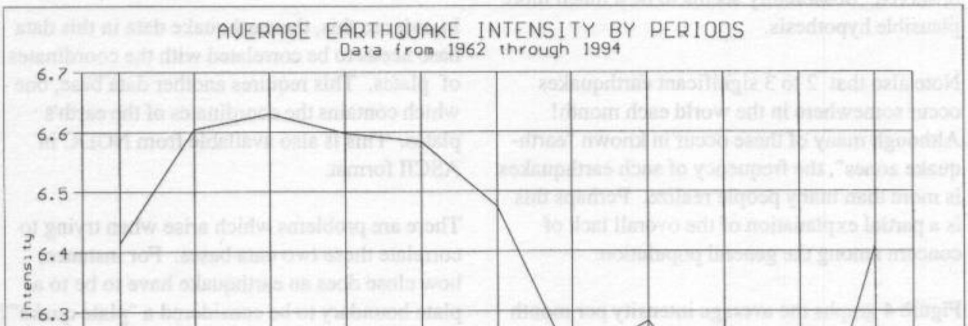

Figure 2.

Weather is very seasonal in character. One might well ask if earthquakes obey some seasonal laws as well. Figure 3 displays the average number of earthquakes in each month over the 33 years from 1962 to 1994. Note the peaks during March, July, and October. Also note the troughs in December, February, May, and August. There appears to be some seasonality in this data, roughly coinciding to season changes. This needs to be examined more thoroughly to determine if this is coincidence or a true pattern.

Of course, it is true that some months have more days than others. However, this is about a 10% difference between the number of days in the shortest month (February) and in the longest months (January, March, May, July, August, October, and December). The differences between the highest and lowest monthly significant earthquake frequencies is much higher than 10%. So the difference in the length of the months does not fully explain the differences observed. Seasonality seems to be a much more plausible hypothesis.

Note also that 2 to 3 significant earthquakes occur somewhere in the world each month! Although many of these occur in known "earthquake zones", the frequency of such earthquakes is more than many people realize. Perhaps this is a partial explanation of the overall lack of concern among the general population.

Figure 4 graphs the average intensity per month over the 33 years in question. Again, note the peaks in January, March, June, October, and (this time) December. June has a peak, rather than July (as with the frequency), but July is not far behind. The troughs occur in February, April, September, and November. Note that this is roughly the same times of the year as the frequency peaks and troughs, except for December. Although February, April, September, and November are short months, this should not affect the averages, because (theoretically) it should be just as likely that a higher intensity earthquake will occur as a lower intensity quake in the additional days the long months have. The differences in these observations seem small, but they are not as small as they appear to be at first, since the Richter Scale is logarithmic rather than linear.

FUTURE RESEARCH

As is well known, most of the quakes can be shown to occur near tectonic plate boundaries. Even more interesting is the fact that most major earthquakes occur around the "ring of fire" (the Pacific Plate). (Garrison 1993)

Because of the correlation between tectonic plates and earthquake zones, it is logical to ask if patterns can be detected by analyzing the earthquake data. Such trends might be used for predicting earthquakes.

In order to this, the earthquake data in this data base needs to be correlated with the coordinates of plates. This requires another data base, one which contains the coordinates of the earth's plates. This is also available from NGDC in ASCII format.

There are problems which arise when trying to correlate these two data bases. For instance, how close does an earthquake have to be to a plate boundary to be considered a "plate quake"? If an earthquake is equidistant from two plates, which plate should it be associated with?

There are also some problems which arise from the determination of the distance from an earthquake epicenter to a plate boundary. Efficiency is a primary concern in trying to automate such a correlation effort. The mathematics of dealing with spherical coordinates is also more complex

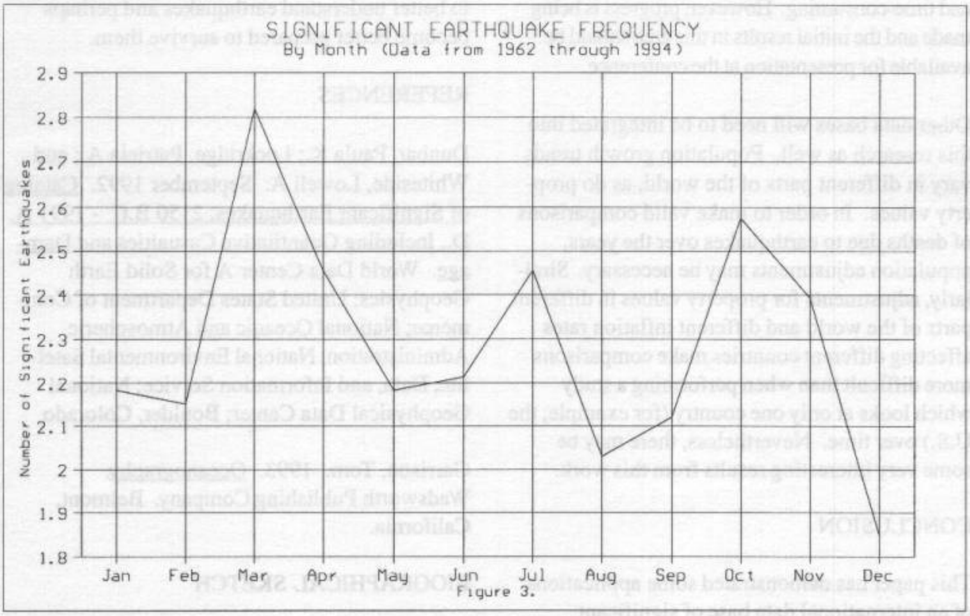

Figure 3.

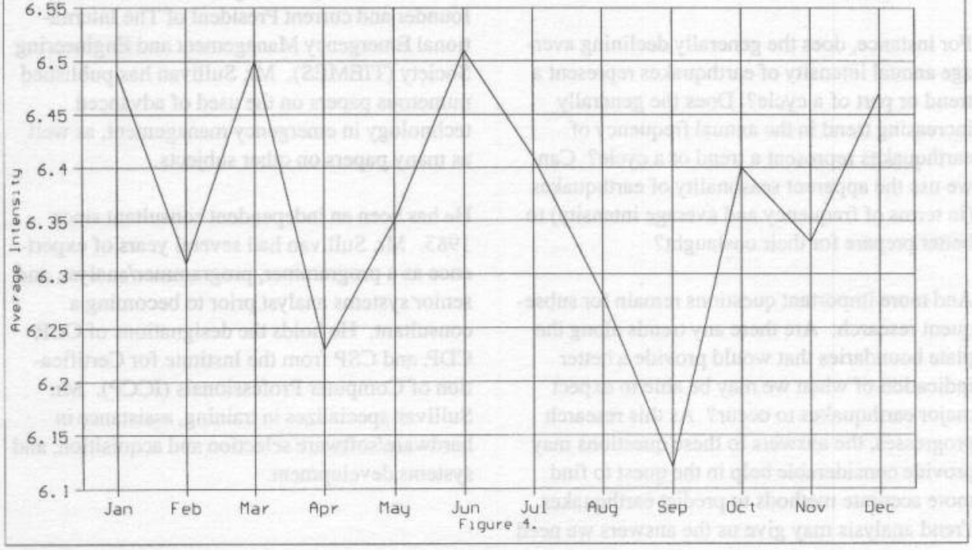

Figure 4.

and time-consuming. However, progress is being made and the initial results in this area should be available for presentation at the conference.

Other data bases will need to be integrated into this research as well. Population growth trends vary in different parts of the world, as do property values. In order to make valid comparisons of deaths due to earthquakes over the years, population adjustments may be necessary. Similarly, adjustments for property values in different parts of the world and different inflation rates affecting different countries make comparisons more difficult than when performing a study which looks at only one country (for example, the U.S.) over time. Nevertheless, there may be some very interesting results from this work.

CONCLUSION

This paper has demonstrated some applications of an international data base of significant earthquakes. Some interesting trends were observed, and may have important consequences for emergency management.

For instance, does the generally declining average annual intensity of earthquakes represent a trend or part of a cycle? Does the generally increasing trend in the annual frequency of earthquakes represent a trend or a cycle? Can we use the apparent seasonality of earthquakes (in terms of frequency and average intensity) to better prepare for their onslaught?

And more important questions remain for subsequent research: Are there any trends along the plate boundaries that would provide a better indication of when we may be able to expect major earthquakes to occur? As this research progresses, the answers to these questions may provide considerable help in the quest to find more accurate methods to predict earthquakes. Trend analysis may give us the answers we need to better understand earthquakes and perhaps become better prepared to survive them.

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BIOGRAPHICAL SKETCH

James D. (Jim) Sullivan has served as a leading organizer for six international emergency management and engineering conferences. He is the founder and current President of The International Emergency Management and Engineering Society (TIEMES). Mr. Sullivan has published numerous papers on the used of advanced technology in emergency management, as well as many papers on other subjects.

He has been an independent consultant since 1983. Mr. Sullivan had several years of experience as a programmer, programmer/analyst, and senior systems analyst prior to becoming a consultant. He holds the designations of CCP, CDP, and CSP from the Institute for Certification of Computer Professionals (ICCP). Mr. Sullivan specializes in training, assistance in hardware/software selection and acquisition, and systems development.

TIEMEC '95

APPENDIX

WATER MANAGEMENT FOR WHEAT THROUGH SOIL MOISTURE SIMULATION USING SPAW MODEL

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KEYWORDS: management, simulation, soil moisture, irrigation.

ABSTRACT

To identify best viable irrigation schedule, i.e. when to irrigate under limited water supply, Soil-Plant-Atmosphere-Water (SPAW) model has been tried to study the impact of water stress on wheat yield under sandy loam at Delhi. The model run has been made for an array of treatments (total 64) combining different sets of irrigation schedule varying from nil to six irrigations at different phenological stages viz: Crown Root Initiation (C), Tillering (T), Jointing (J), Flowering (F), Milking (M) and Dough (D). In all treatments, soil is considered to be at field capacity level at the time of sowing. Water use efficiency (WUE) was considered as a basis to formulate intensity of irrigation.

The estimated maximum yield by model depicting the most productive irrigation schedule for 1, 2, 3, 4, 5 and 6 number of irrigations are 1.5, 19.8, 31.2, 37.3, 40.7 and 43.3 q/ha respectively. The results of the experiment suggests that it is advisable to irrigate at T; T-J; T-J-F; T-J-F-M; T-J-F-M-D; C-T-J-F-M-D respectively for 1, 2, 3, 4, 5 and 6 number of irrigations to harvest the maximum yield. Results indicate that moisture stress at tillering affect the crop yield most severely, hence it is not advisable to skip irrigation at this stage. Jointing, Flowering and Milking succeed in the order of preference. The prime schedule with four irrigations (T-J-F-M) produced 37.3 q/ha of yield. The enhancement in the yield level through one additional irrigation is only by 9% over four irrigation treatment. Further, application of irrigation at all six stages lead to elevate the yield level by 7% over five irrigation treatment. As the increment in the yield of wheat through 5th and 6th irrigation is marginal, it may be more profitable for those farmers who have got ample land holding with limited water resource to grow wheat with four irrigations and raise crops having low water requirements (like Brasicca, Blackgram etc.) with the water saved from curtailing two irrigation on wheat.

INTRODUCTION

Wheat farming in India has been almost revolutionised with the introduction of the high yielding dwarf wheat varieties in 1963-64. The dwarf varieties are highly responsive to irrigation and fertiliser applications. Irrigated agriculture has traditionally been considered as a method of bringing stability to crop production through reduced yield variability. In dry regions where water availabilty is limited, irrigators want and need to efficiently utilize irrigation water applied. One aspect of improved irrigation water management strategy centres on the use of irrigation scheduling. The most practical criterion commonly adopted by the farmers for scheduling of irrigations to wheat is the one based on the physiological growth stages critical in demand for water. Gautam *et al.* (1968) working on the sandy loam soils of Delhi observed that four irrigations applied at proper stages of crop growth yielded as much as an intensive irrigation practice with six irrigations. Chauhan *et al.* (1970) also working on the sandy loam soils of Delhi investigated that yield of wheat did not increase in proportion to the increase in number of irrigations and at each frequency the irrigations applied at some growth stages were more beneficial to the wheat than those applied at the other stages. Most of the workers have observed that in case of dwarf varieties of wheat, irrigation at C stage (22 days after sowing-DAS) resulted in the maximum production per unit of water applied and therefore this stage was considered as the most critical stage for irrigation (Dastane and Patel 1968; Yadav 1972; Michael and Pandey 1975). Critical periods for soil water stress for wheat are possibly during booting and heading and two weeks before pollination (FAO 1986).

The information on critical stages is useful in areas with limited water resources where maximum WUE is aimed at. But due to ,firstly, vast variability of genotypes, soil and atmosphere, it is not possible to conduct agronomic experiments for every situation and make valid recommendations, and secondly, monitoring soil moisture profile dynamics on a real time basis is not always possible, *crop simulation models* have been used increasingly in the economic analysis of irrigation management, practically irrigation scheduling. These models explicitly represent the dynamic aspect of crop water use and response governed by soil and genotype. Also, environmental influences are an explicit part of simulation model. This feature allows for the application of the model to a wide range of genotype, soil and environmental condition. Optimization of irrigation management stratagies and systems using crop simulation models has been actively pursued by many individuals (Bernardo *et al*. 1988; Rao *et al*. 1988; Epperson *et al*. 1993). The major objective of this study is to use SPAW model to compare various irrigation management stratagies to identify the best viable irrigation schedule for wheat crop under limited water supply in dry land.

MATERIAL AND METHODS

Model: The SPAW model developed by Saxton *et al*. (1974) was chosen for use in this study because the technique is relatively simple, with reasonably sound physical base and incorporates sufficient degree of detail with minimal requirements of daily inputs consisting of routinely measured meteorological data. This model has been found to adequately describe, integrate and relate the plant-soil-atmosphere processes as demonstrated by several applications (Sudar *et al*. 1981; Saxton and Bluhm 1982; Rathore *et al*. 1994; Singh *et al*. 1995).

The model computes a daily soil water profile budget by considering weather input, crop growth status and soil profile water holding characteristics. Daily estimates of three components of actual evapotranspiration (ET), interception evaporation, soil water evaporation and plant transpiration, are obtained by a complex set of relationship representing the current status of soil, plant and weather variables. The water budget is completed by considering runoff, infiltration, soil water redistribution and percolation at the lower soil boundary.

A cumulative water stress index (WSI) for the growing season was computed as shown below

$$WSI = (1-Tai/Tpi) * YSi \quad ...(1)$$

where n is number of days of growing season, Tai and Tpi are daily actual and potential transpiration measurements and YSi is yield susceptibility factor. The end of season water-stress index was related to yield using the following linear relationship reported by Sudar *et al*. (1981):

$$Ya = Ym - Bi * WSI \quad ...(2)$$

where Ya and Ym are actual and maximum yields,Bi is the regression coefficient.

Model calibration: Rathore *et al*. (1994) has calibrated and tested this model for irrigated wheat at Delhi using prescribed information on wheat growth characteristics and soil alongwith daily weather data for 11 wheat crop seasons (1979-80 to 1989-90) recorded at IARI, New Delhi observatory. The model is able to simulate the observed fluctuations in moisture content of different layers of soil profile reasonably well and brings out the general pattern of observed variations in actual evapotranspiration.

In order to calibrate the stress-index subroutine, yield susceptibility values for wheat at different growth stages as developed from data reported in literature (Gajri and Prihar 1985; FAO 1986) are given in Table 1.

Table 1

Yield suceptibility to water stress Vs. crop age

DAS	0	10	25	30	40	50	60	75	80	90	100	120	130	150
YS	.0	.20	.35	.25	.25	.30	.40	.45	.40	.30	.20	.10	.05	.00

A daily water stress value was multiplied by the yield susceptibility value for that date and these quantities were summed over the growing season (equation 1) to provide an accumulated WSI. Thus the accumulated WSI values at the end of the crop season were computed for 11 consecutive crop seasons and correlated with actual observed crop yields (Source: India Meteorological Department station at WTC, IARI). The results showed reasonable agreement between yield reduction and the computed WSI ($r = -0.92$) and corresponding regression equation was found to be

$$YIELD = 50.9 - 5.69 * WSI \quad ...(3)$$

Experiment conducted: In the present study an experiment was conducted for wheat crop under sandy loam soil of Delhi which falls in the North-Western Plains Zone of India (ICAR 1980). Here the irrigated wheat is planted in November and beginning of December and harvested by the second fortnight of April. The crop season 1984-85 was chosen because there were practically no rains except in second week of April 1985. Weekly weather conditions from November, 1984 through April, 1985 are given in Table 2.

Table 2

Weekly Weather data for wheat crop-season (Nov.-Apr.) 1984-85recorded at Delhi

Month/ Week	Rain-fall (mm)	Tmax (deg.C)	Tmin (deg.C)	Evapo-ration (mm/day)
Nov 5-11	0.0	29.5	10.8	3.7
12-18	0.0	29.1	9.9	3.2
19-25	0.0	28.1	10.1	2.7
26-2 Dec	0.0	25.3	7.4	0.7
Dec 3-9	0.0	25.5	6.9	1.7
10-16	0.0	25.0	7.8	2.7
17-23	0.0	22.4	4.4	3.1
24-31	0.6	21.2	6.2	2.0
Jan 1-7	0.0	16.9	7.4	1.5
8-14	0.0	19.6	5.3	1.8
15-21	0.0	20.4	7.1	2.5
22-28	0.0	21.9	6.7	2.4
29-4 Feb	0.0	22.8	5.4	2.9
Feb 5-11	0.0	24.1	5.9	3.3
12-18	0.0	24.8	5.0	3.8
19-25	0.0	27.7	8.6	4.9
26-4 Mar	0.0	29.9	11.2	5.2
Mar 5-11	0.0	31.5	12.2	5.3
12-18	0.0	32.1	12.5	6.4
19-25	0.0	31.6	14.7	6.1
26-1 Apr	0.0	35.7	17.5	6.7
Apr 2-8	0.8	34.7	18.9	6.4
9-15	5.0	35.3	18.1	5.9
16-22	0.0	39.4	20.0	7.9
23-29	0.0	40.3	20.6	9.8

Sowing was done on November 27, 1984 in rows 22.5 cm apart. Fertilizers were applied as per recommended package. The crop was harvested on April 12, 1985. This data det pertains to the research farms of IARI, New Delhi. In order to assess the effect of varying schedule and frequency of irrigation on yield, the model run was made for an array of treatments (total 64) combining different sets of irrigation schedule varying from nil to six irrigations at different phenological stages viz. C (22 DAS), T (45 DAS), J (65 DAS), F (85 DAS), M (105 DAS) and D (120 DAS). In all treatments soil is considered to be at field capacity level at the time of sowing. For each simulation, an end of growing season WSI was computed which was used to predict the yield using the equation (3).

RESULTS AND DISCUSSIONS

The relationship as given by equation (3) assume a potential yield of 50.9 Q/ha. The 8.9 units of WSI or more are assumed to produce no yield i.e. crop undergoes severe stress during the vegetative and reproductive phase and finally dies. Results from the experiment for varying schedule at different frequency of irrigation are discussed frequencywise:

No irrigation - crop suffers from severe stress and does not survive. Nonetheless, it is worth to analyse the status of the soil moisture in the root zone vis-a-vis WSI during different phenostages. Soil water in root zone was 60% and 45% of maximum available soil moisture (ASM) at C and T stages. Crop water requirement was met fully up to C because optimum depletion limit of ASM for wheat has been observed to be about 40 to 50% in the surface 60 cm depth on the sandy loam of Delhi (IARI 1977). A nominal stress was developed during pre-tillering phase leading to give WSI 0.15 at T stage. It is tillering and onward, plant starts facing water stress as reflected in daily stress value. On average plant water requirement satisfaction are 75%, 45%, 30% and 20% during the periods T-J, J-F, F-M and M-D respectively. The relative impact on yield of water stress at different stages are reflected in accumulated WSI i.e. 0.04 units at C, 0.15 units at T, 2.14 units at J, 6.83 units at F, 10.58 units at M and 12.25 units at D stages.

One irrigation - crop yield is not economically viable, nonetheless, results indicate that irrigation at T or J is preferred to that at CRI stage. The logic is that irrigation at T or J stages would make the crop enter into reproductive phase and thus lead to give some yield. It is too late to irrigate at F, M or D stage as crop will die by then.

Two irrigations - crop does not survive if either first irrigation is held up to F or M or first applied at C followed by a long gap (80 DAS). First irrigation at C followed by second at F makes drastic reduction in the yield. Therefore, in case of two irrigation the first irrigation at C is not important because soil moisture at this stage is above the threshold limit. To obtain higher yield, it is therefore recommended to provide first irrigation just after T or J followed by second in succession.

Three irrigations - results indicate that one can not afford to apply first irrigation at F stage or beyond. Poor yield is harvested if the first irrigation is provided at C and subsequently long gap is there till F. Crop performed even worse if second one is awaited till M causing still longer dry spell. Higher production is achieved if the first irrigation is applied at T and providing remaining two in succession i.e. J-F or J-M.

Four irrigations - avoiding irrigation at T and J leads to comparably poorest yield. Maximum yield is obtained when four irrigations are applied in succession from T stage. Skipping of irrigation is recommended in the beginning (C) and towards the end (D) of the crop period.

Five irrigations - results indicate that deleting one irrigation at either C or D has the least effect on the crop production, hence skipping irrigation should be preferred in the order of D through T.

The best combinations of phenological stages at different frequency of irrigation schedules alongwith their maximum yield, hence called the prime schedule of irrigation, are given in table 3. It is clear from the table 3 that there is a significant increase in the yield if farmers move from one to two irrigations. Yield increases further with increase in number of irrigations from two through six, but the response to irrigation, i.e. WUE, decreased gradually up to four irrigation and sharply thereafter.

Table 3

Prime schedule of irrigation giving maximum yield for diffrent number of applications

Frequency of irrigation	Prime schedule of irrigation	Yield Q/ha
Nil	-	0.0
One	T	1.5
Two	T-J	19.8
Three	T-J-F	31.2
Four	T-J-F-M	37.3
Five	T-J-F-M-D	40.7
Six	C-T-J-F-M-D	43.3

It is not affordable to skip irrigation at Tillering which emerged to be the most CRITICAL STAGE. Jointing, Flowering and Milking succeed in order of preference. The prime schedule with four irrigations (T-J-F-M) produced 37.3 q/ha of yield. The enhancement in the yield level through one additional irrigation is only by 9% over four irrigation treatment. Further, application of irrigation at all six stages lead to elevate the yield level by 7% over five irrigation treatment. Under the circumstances if available water is not enough to meet the suggested prime schedule, the farmers can even plan for 3 number of irrigations loosing yield only by 16%.

CONCLUSIONS

Tillering is the most critical stage followed by Jointing and Milking. Hence adequate moisture level in the root zone at these phases is mandatory for obtaining good yield. As the crop enter senescence, the impact of moisture stress on yield is toned down. Also, depletion in soil moisture level at Crown Root Initiation does not seem to be critical due to low evapotranspiration rate. Hence, one may prefer to choose skipping irrigation at this stage over T, J, F and M stages under limited water supply. As the increment in the yield of wheat through 5th and 6th irrigation is marginal, it may be more profitable for those farmers who have got ample land holding with limited water resource to grow wheat with four irrigations and raise crops having low water requirements (like Brasicca, Blackgram etc.) with the water saved from curtailing two irrigation on wheat.

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