DECISION SUPPORT SYSTEMS FOR THE PREVENTION OF SLOPE RELATED NATURAL HAZARDS: A PERSONAL VIEW ON THE FRENCH SITUATION

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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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