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AN ADVANCED DSS FOR MANAGING TUNNEL EMERGENCIES.

Verner Andersen, Frank Markert and Steen Weber
Risø National Laboratory[1]

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Abstract

Based on the number of accidents in European tunnels during recent years, the need for an advanced decision support system for the managing of tunnels has been affirmed. As a result, a European project, SIRTAKI[2] (Safety Improvement in Road & rail Tunnels using Advanced ICT and Knowledge Intensive DSS), has been launched. The goal of SIRTAKI is to develop a decision support system for the managing of tunnels during normal operations and during emergencies. The project is currently in its initial phase. This paper gives an overview of the SIRTAKI project, specifies the use of scenarios for creating training sessions, and outlines the plan for evaluating the final product.

A method for classifying the user requirements and for planning the system evaluation, the means-end hierarchy, will be presented.

Introduction

The geographical characteristics of Europe have historically led to the construction of very long road and railway tunnels for the transport of passengers and freight. Many of these tunnels were built decades ago and have now become insufficient to properly serve the increasing mobility needs of European countries.

The increase of the demand, the obsolescence of the installations, and the lack of an integrated management of emergency situations, are leading to acute security problems in European tunnels, as was dramatically proven in the recent examples of the Mont Blanc and Tauern tunnels.

A recent international study [1] on 25 of these tunnels, in Austria, Belgium, Germany, Spain, Switzerland, France, United Kingdom and Italy, concluded that one third of the analysed tunnels do not meet the minimum security requirements to face an accident.

Together with safety and efficient emergency management, the effective integration of the tunnel surveillance and control with the rest of the urban or interurban network management is a must.

A discoordinated management of the network with respect to the tunnel provokes congestions and even potentially dangerous situations; likewise, if the tunnel manager ignores the network situation – including the management strategies being applied - he can take counterproductive decisions that have a negative impact both on the tunnel safety and on the overall network performance [2].

[1] Systems Analysis Department, DK 4000 Roskilde, Denmark,
e-mails: verner.andersen@risoe.dk. frank.markert@risoe.dk, steen.weber@risoe.dk
[2] SIRTAKI is an EU project IST-2000-28303, and is partly funded by EU

To summarise, tunnel safety is a key issue and tunnel managers often face emergencies that demand rapid and appropriate reactions – involving complex decisions - in order to avoid catastrophes. These actions have to be effective whilst maintaining coordination between the management of the emergency and the management of the surrounding network.

In this context, SIRTAKI plans to respond to these needs by the development and assessment of an advanced tunnel management system that specifically tackles (i) safety issues and emergencies and (ii) integration within the overall network management.

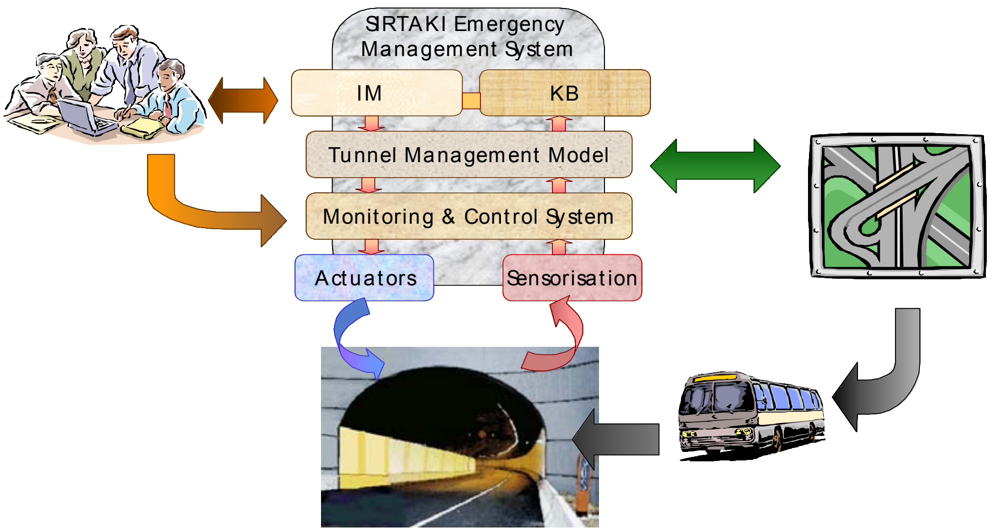
This strategic goal will be translated into a set of measurable, specific objectives:

1. To develop an integrated prototype of tunnel management and decision support system (DSS), including – but not limited to - emergency management. This prototype will be composed of four modules:
    a. Knowledge Basis: a learning tool that will support training, decision taking and automation of actions by applying previous experiences in emergency management and simulation of emergency situations.
    b. DSS: a smart decision support system that will help crisis managers to take decisions in emergency situations.
    c. Tunnel Management Model: a model of the tunnel that enables the integration of traditional surveillance and control systems with, on the one hand, DSS and KB and, on the other, the overall transport network.
    d. Tunnel surveillance and control system. SIRTAKI approach will not substitute traditional surveillance and control systems, but will enhance them with new capabilities, such as the DSS and KB, which will make control systems more efficient.
2. To integrate and validate the SIRTAKI results in a set of test sites with different characteristics and requirements (urban/interurban, road/railway, etc.) in France, Germany, Italy and Spain.
3. To establish a methodology and accompanying guidelines to facilitate the cost-effective adoption of the project results by any tunnel operator in Europe.

System architecture summary

The system to be developed in SIRTAKI is outlined in the following figure:

Figure 1: System to be developed in SIRTAKI



The benefits expected as a result of the Project are measured in technical, social and economic terms. Several benefits can be described including, first, the improvement of safety in tunnels, through a reduction in the risk and severity of accidents. Second, stress in operators and citizens during an emergency will be reduced. Third, the tunnels and the transport network will be managed in a coordinated way, which will improve performance of the transport infrastructures. Finally, the Project will allow for the performance of integrated management not only during emergencies, but also for other special situations.

The following preliminary indicators have been defined to illustrate how the project achievements will be quantified and measured: user satisfaction and acceptance (to be evaluated through questionnaires); reduction of response time to detected incidents (including the comparison with the situation without SIRTAKI); rate of false alarms; number of non-detected emergency situations; and user's assessment of the proposed corrective actions. The full set of indicators will be produced during the preparation of the Evaluation Plan - and after having elicited the user needs and requirements.

Road tunnels versus rail tunnels

Rescue operations are difficult in tunnels, as the possibilities to reach the emergency location may be limited due to large smoke generation and heat from fires and the blockade of "entrances". Here rail tunnels give more problems than road tunnels. The two systems are not comparable with each other due to their different concepts. The major reasons for accidents for the road traffic are due to human factors, which are increased by the nature of road traffic. Safety systems that are possible for the rail traffic are not applicable for the road traffic, as road traffic is driving "only on sight", safety measures are missing, and the road traffic includes a high number of ignition sources. The large number of individual drivers increases the possibility of subjective and unpredictable actions. Here rescue operations needs to stress self- and assisted rescue (by e.g. fire brigades). The fuel in the cars increases the fire load remarkably, and there is increased likelihood that the tunnel will be blocked by the accident. Fire extinguishers are seldom placed in cars and the drivers are untrained in using such devices. Furthermore, in Europe today it seems that a common citizen is very much used to and expects to get help and therefore, most persons will wait to be instructed without taking their own initiative. This is shown by investigations of the latest tunnel accidents, which showed that people would stay in their cars waiting for the rescue personnel to give advice.

The rail system with the tracks, driving by distances, safety systems including the modern guidance and safety technique, and the presence of trained personnel makes it possible to stress measures that decrease the probability of incidents/accidents and to mitigate the consequences of such situations.

Accident types

An accident is often the result of a number of succeeding or interacting factors, and when it happens it may be without serious harm in terms of injuries to people, structural integrity of the tunnel itself, and to the environment. In other situations a number of people may be harmed very seriously due to the mechanical impact of, e.g., a car crash or train de-railing, or a fire initiated by a technical defect. In some of these situations the accident does not "stop" at this stage, but propagates, as the initial accident may start a fire and/or an explosion or a fire from e.g. a technical defect gets out of control. This may give raise to toxic emissions from the cargo or the fire (toxic combustion gases). Other loads may be released in the tunnel air or are floating on the road to the deepest point of the tunnel. This can result in toxic emissions at longer distances from the accident. In case of flammable substances released, delayed fires and/or vapour cloud explosions may occur. The pressure of the blasts and the high temperature of larger fires may also damage the structural integrity of the tunnel. In terms of rescue and evacuation of the people in danger, the position in the tunnel where the accident occurs is another important factor, as emergency exits may be blocked or liquids may - depending on the actual slope of the tunnel - float “back” towards the waiting cars. Factors that also could have an influence will be the proper regulation of the ventilation systems and the functioning of the emergency lights. “Crowded” situations were many people have the same destination e.g. for football matches, large demonstrations, or cultural events can further influence the situation negatively. Thus a huge number of factors have to be taken into consideration when useful training scenarios are to be developed and knowledge is required on daily situations and unexpected events. Such knowledge may be specific to each tunnel and therefore it is important to have direct input from the accident history of the specific site in question. Other sources in which to find relevant information to build training scenarios are based on real accidents that have happened. Therefore, it is very useful to analyse accidents that occurred in other tunnels and to elucidate the relevant information and history of each accident. Here it is necessary not just to apply the information, but it needs to be adapted to suit the differences of the installations (physical parameters of the construction, typical weather conditions, exact location of the accident in the tunnel (distance from exits, ventilation systems and slope of the road) and distances to emergency exits, alarming systems etc.).

Use of scenarios

Scenarios are very effective as a means of getting realistic conditions and environments for coping with various types of situations. These could be daily routine situations or unexpected safety critical events. For these events, swift, efficient, and well structured efforts are of vital importance for minimising the consequences of the event, from a short term point of view or a long term perspective.

The development of training scenarios will often be based on requests for the need to obtain specific abilities and sufficient skills when dealing with specific situations for the persons being involved in the training session. This may speed up the skill as compared with the traditional hands on experience obtained by the daily routine.

The training of managing organisations are often based on repeated events or recent real accidents or training sessions, which may have revealed a less than optimal performance of the organisational team in specific situations. However, even though such situations may not necessarily trigger the training session itself, they may give rise to the objectives of the next training session as related to the specific goals of coming sessions.

Training scenarios are very efficient for performing emergency response training as the scenarios may support specific adaptable training objectives. Furthermore, the scenarios may be implemented in a dynamic way; i.e. the events included in a given scenario may be currently adjusted in order to keep the training along the lines originally intended.

As mentioned, training scenarios are often based on recent real accidents with the emphasis on training of specific tasks on which improved performance is desired. Thus, even though training is often demanded by the emergency preparedness plans, the goal of training is not to fulfil this demand, but to achieve an improved future personal performance in real emergency situations.

A scenario constitutes a story of a possible occurrence of events threatening to the society and/or the environments. A scenario ought to give the trainees the same kind of experiences and need for taking strategic decisions, as well as a need to exhibit creativity, insight and intuition, as in a real emergency situation. Therefore, it is of vital importance that the scenarios are plausible, but at the same time they may very well be surprising in order to create challenges to the trainee when coping with unexpected time critical situations and decisions. As the scenarios are meant for education and training, they should involve issues of which the outcome depends critically on timely and successful decisions.

The scenario is meant for ordering the visual perception of critical situations on which the emergency management response will be based. Therefore, despite the fictional presentation, this should in no way be a fixed sequence of events coming up at predefined times along the story line, but it should reflect and adjust to all the actions taken by the trainees in order to cope with the accident. So, the process should be highly interactive during the execution of the scenario, and this must be reflected in planning the scenario by the training supervisor.

The process for the supervisor of developing a training scenario begins by having in mind – based on previous experience from real life performance or training sessions - the tasks the trainees need to train. The next step is to identify the environments, situations, and other driving forces that create the mental input necessary for the trainees to provoke further gathering of information and knowledge for making the decisions to remedy the conditions and diminish the consequences of the hazardous situation.

Besides generating the physical location of the emergency, the time of the day and the direction and strength of the wind must be settled. The wind in tunnels, which may create a chimney effect, may influence the situation in case toxic material or smoke will be dispersed from the source of the accidents. Finally the specific accident must be incorporated in the scenery.

The scenario should be built as a scenario script allowing various paths through the sequence of possible events. The actual path will be based on the actions of the trainees and hereby result in various outcomes of the emergency situation. Thus, the scenario script may be seen as an event tree composed by nodes and arcs connecting different nodes. At each node the choice of path in progressing the scenario will be decided either by the previous or actual actions taken by the trainees in order to cope with the hazardous situation, or, alternatively, the supervisor may be able to decide how to progress the scenario in order to guide the scenario as he finds most appropriate in relation to the training objectives. Likewise, he may use this possibility if he finds the need to strengthen or facilitate the scenario depending on the ability of the trainees to cope effectively with the accidental situation. Furthermore, the event tree may act as a reminder to the supervisor, acting as a tool for implementing information to the supervisor in the form of notes related to the status and the progress of the scenario.

Scenario selection

The selection of scenarios for the various demonstrations will be based on the user requirements and specific wishes from the end-users related to their specific tunnel. They may be selected based on previous accidents or training events having a less than optimal outcome. Training scenarios will preferably be selected among scenarios tried out before with a well-known result and the possibility for the responsible of the training session to compare with the outcome without SIRTAKI. Therefore, these scenarios will be defined in co-operation with the end-users related to the specific demonstration sites.

Examples of types of training sessions could be:

Plain tunnels:

- Accident with fire outside the tunnel;
- Accident with fire inside the tunnel;
- Collision between a car and a truck in a road tunnel with or without fire and/or escape of toxic material;
- Collision between two trains in a rail tunnel with or without fire and/or escape of toxic material;

For Metro tunnels the scenarios may be more specific, like:

- Automatic fire alarm in trains at the station;
- Automatic fire alarm at stations or in emergency exits;
- Alarms initiated by cellular GSM phones from passengers;
- Fire in train in the tunnel between two stations;
- Fire in train at an underground station;
- Fire in tunnel installations
- Fire at stations and in emergency exits;
- Personal run-over or train accident including 1 – 10 injured persons;
- Train accident with more than 10 injured persons;

Evaluation Plans

The validation methodology of SIRTAKI will be based on user/system interaction in demonstrations using selected scenarios. This methodology will include (a) Guidelines for the definition of the scenarios at the demonstration and (b) Guidelines for specifying the data selected, how these data will be analysed, and how the results will be presented.

This point describes the 'Evaluation Plan', which the demonstrator sites will use to assess the objectives identified within SIRTAKI. Four main categories of assessment are defined:

- Testing the physical functioning of the system (or technical evaluation).
- User acceptance (friendless).
- Impact analysis (socio-economic aspects) and
- Financial evaluation and cost-benefit analysis.

This 'Evaluation Plan' specifies the framework to be used across the different demonstration sites and ensures that common procedures and indicators will be used. This will enable a cross-site comparison of results to be undertaken and to provide added value by generalising results throughout Europe.

Specifying objectives, the 'Evaluation Plan' describes the indicators necessary for obtaining valuable indicator values that are to be used by the demonstration sites. In addition to these common testing methods, each site may undertake additional tests based on specific local needs or services.

The means-end hierarchy

In order to facilitate the evaluation of the SIRTAKI outcome, the user requirements will be categorised in terms of means-end relations. The framework for this categorisation is shown in the figure below, presenting by the middle column the hierarchy in general [3,4] and by the left-hand column the means-end hierarchy in a condensed form utilising fewer levels in the hierarchy. This representation has proved successful and sufficient for evaluation purposes [5], and will be utilised in the SIRTAKI project, indicating the strategic goals on the highest level, procedures supporting these goals at the next lower level, and – at the lowest level – the operations from which these procedures are created. In this representation each level will be specified by the next upper level concerning the reason or background for an action, and by the next lower level concerning how this action may be supported (see the right-hand column).

Figure 2: Means-end relations in condensed form to be utilised for user specifying requirements in SIRTAKI, and in general with indication of the relation among the various levels

User	Means- End	Interrelations of levels
Strategic requirements	Functional Purpose	Why
	Abstract Function	Why What
Procedural requirements	Generalized Function	Why What How
Operational requirements	Physical functions	What How
	Physical Form	How

The Means – Ends hierarchy was originally developed to describe the different abstraction levels in a working situation. The highest level corresponds to the system objectives, and the lowest level corresponds to the physical form used to implement the next higher level. The connections between the levels are expressed in the Interaction column where, at a given level, we can ask the question 'What' are we doing. At the next higher lever we may be informed about 'Why' it should be done, and at the next lower level get the answer to 'How' it may be done.

In the SIRTAKI project we have condensed the Means – Ends hierarchy to 3 levels. If we think of the SIRTAKI system as a collection of software modules then these modules will be at the lowest level "Operational". A combination of modules will belong to the "Procedural" level carrying out some higher-level tasks. Finally, the interaction of the whole system will fulfil the "Strategic" level in the hierarchy.

Having the user requirements classified according to the levels outlined above, the following evaluation steps may then be followed.

System evaluation normally constitutes three levels of test procedures:

- Verification, which is a check of implementation of operations specified in the user requirements, and therefore directly related to the lower level of the hierarchical representation of user requirement.
- Evaluation, which is a check of the presence of the functionality specified in the user requirements, i.e. is the system capable of executing all the sequences of operations needed for fulfilling the goals specified in the requirements. This part of the test procedure is directly related to the middle part of the hierarchical presentation of the requirements, the procedural requirements.
- Last, but not least, the validation takes care of – based on user satisfaction – the test of whether the system is of any value to the end users, i.e. do they perform better, more efficient and with lower risk for making mistakes in a critical situation than without having the system available. The question here is the difference between developing the system

right, i.e. following carefully all the elicited requirement specifications, or developing the right system, i.e. a system that really – in real life – is of benefit for the end users.

The logical way of evaluating a system is to take the top-down approach in which the evaluation and validation is tested by user interaction with the system. In case this test does not end up satisfactorily the next step would be to take the bottom-up approach, starting with the verification phase, checking the implementation of operational features and continuing with check of the functional features.

So, the SIRTAKI system evaluation will be based on the top-down approach resting on system to user interaction.

In more detail the 'evaluation and validation' of the SIRTAKI system will be performed by letting groups of test persons solve various tasks related to selected scenarios. The evaluation is partly based on measures, concerning the benefit from using the system related to:

- assessment of the current state and the current prognosis for the influence of the hazardous situation to people, tunnel integrity, and the environment;
- assessment and possible revision of the current priority of overall goals (which goals require relatively more attention and resources now?);
- assessment of the need for additional actions and agents: decision whether to alert additional agents or organisational units;
- establishment of communication links with the units and agents;
- planning of actions for coping with the accident or minimising the consequences;
- distribution of tasks and co-ordination of information to the relevant units and agent;
- executing the remedying plan.

Furthermore, the evaluation is qualitatively based on the users' subjective assessment of using the system and of the outcome of their efforts. This is done through direct interviews and through fulfilment of detailed questionnaires enlightening the general impression and understanding of the SIRTAKI system.

Conclusion

The outcome of the SIRTAKI project will be generalised for use in various tunnels, and for the future, hopefully specify the standard for emergency management in European tunnels.

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Author Biographies

Verner Andersen got his Ph.D. in Physics in 1969. He is a Senior Research Scientist since 1992 at Risø National Laboratory. He has since 1986 been responsible as project manager and co-ordinator of various international projects related to decision support and training related to emergency management. His research topics include man-machine interactions and human factors.

Frank Markert got his Ph.D. in 1993 in physical chemistry. He is a Senior scientist at Risø National Laboratory. His work is mainly concerned with risk assessment and consequence analysis of complex industrial installations, hereunder the assessment of fire emissions. Presently, he is in charge as the co-ordinator to organise the Danish branch and the fire cluster in a European network on process safety -Safetynet (chemistry) and member of the network's steering committee.

Steen Weber got his PhD in reactor physics in 1974. Since 1990 he is a member of the System Analysis Department. He is a Senior Scientist at Risø. He has been local project leader of projects in which various knowledge-based systems were developed. His main research interests are in the development, implementation and evaluation of human-computer interfaces.