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An Analytical Tool For Assessing The Performance Of The Emergency Preparedness Machine

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The success of emergency response relies on proper emergency preparedness activities to define areas of responsibility, roles, and effective interventions. In this perspective, software tools can be of paramount importance in supporting the decision making process, since the involved authorities are forced to consider the multifaceted factors characterizing the emergency preparedness and response. Specifically, the manuscript focuses on two complementary risk typologies: mounting risk (*i.e.* floods) and sudden risk (*i.e.* flash floods or tunnel accidents). The Authors developed a program, which assesses the vulnerability of an inter-organizational civil protection structure by analyzing a number of parameters that pertain to physical, organizational, and contextual features. The Analytical Hierarchy Process methodology, AHP, was applied to the emergency preparedness problem so to structure the available alternatives into a weighted multi-criteria framework while evaluating the performance indexes, and expressing the performance of the emergency system within a specific context.

1. Introduction

When an accident occurs, civil protection actors must take decisions quickly, often based on incomplete and ambiguous information about the unfolding event and its location (Paton and Flin, 1999). The minimization of social and physical damages is feasible by using emergency management systems that try to control possible dangerous effects by supporting the emergency staff against the potentially high stress components. Emergency Plans include emergency management systems to facilitate the emergency response under exceptional circumstances and organize the multi-disciplinary competences while sharing the available materials and human resources. To facilitate the development of emergency response systems, intra- and inter-organizational coordination and integration must be improved. This improvement can be achieved by focusing on internal and external vulnerability elements of each organization. To support the decision-making processes and the implementation of the consequent actions during an emergency, strategic models that emphasize strong points and highlight criticalities are needed. Such emergency response models may enhance the integration among actors involved in the emergency preparedness, especially by focusing on the communication and information exchange among civil protection institutions and between them and citizens.
Consequently, the success of the emergency response relies on proper emergency preparedness activities devoted to defining areas of responsibility, roles, and effective

interventions. The emergency preparedness activities allow making easier the decisions during the emergency response due to the high knowledge about possible risk scenarios and available resources for managing the emergency. In addition, information about actions to be performed rapidly is facilitated when social coordination and communication efforts are preemptively developed.
The following sections will delineate a way for supporting the actors involved in the emergency preparedness and identify the aspects affecting the performances of the emergency response. Afterwards, we will describe the Analytic Hierarchy Process (AHP), a mathematical framework for ranking the possible alternatives and evaluate some performance indexes of the system under study.

2. Problem Statement

Emergency response, supported by preparedness activities, is a complex task that calls for technical tools able to assess the intra- and inter-organizational structure dealing with crises. Software tools may be of paramount importance in supporting the actors, in particular for the multifaceted and interlinked factors characterizing the emergency response. In fact, the actors' decisions and actions are based on the analysis of structural, physical, organizational, human, and contextual aspects.
A safety computer program is as technical tool to evaluate the organizational and inter-organizational asset of a multi-actor civil protection group. The main objective of this tool should be the assessment of hazardous and vulnerable characteristics of both social and physical environments where the accident occurs.
The software we developed is a Decision Support System to support the estimation, evaluation, and comparison of alternatives in the organization of emergency preparedness. In fact, it represents a computer-based information system to help decision-making by choosing among alternatives based on expert judgments/opinions.
The paper describes a dedicated software tool, named "Evaluator", with the aim of highlighting strong and vulnerable elements of civil protection structures and improving emergency preparedness in case of:

- tunnel accidents either in national or trans-national contexts, according to the recent European legislation (Directive 2004/54/EC);
- the flood risk.

Nevertheless, the Evaluator is conceived to deal also with other risk typologies, either sudden or mounting risks.
The Evaluator allows identifying hazardous elements while assessing both internal and external resources to manage the emergency, by focusing on the availability of specific professional and organizational capabilities. All these features are collected to evaluate the emergency preparedness by identifying a "final score" that expresses the quality of intra- and inter-organizational coordination. Consequently, this tool should be used in the phase of emergency preparedness to highlight criticalities and investigate possible corrective actions to improve the level of coordination and the capability of performing tasks.
To judge a civil protection group, the Evaluator takes into account aspects pertaining to different areas, *i.e.* we have a multi criteria problem. These main areas are gathered and described in Table 1. The categorization of the aforementioned parameters is necessary

in order to group similar characteristics and, consequently, to compare features related to the same area. Notice that not all the parameters pertaining to the aforementioned areas have the same relevance in determining the performance of the emergency response. Therefore, such a categorization allows discarding the least important while singling out a weighed scale of indexes.

Table 1: Categorization of emergency preparedness aspects for quality assessment

Areas	Description	Tunnel Accidents	Flood Risk
Physical Features	Physical characteristics af the accident location and present equipment	Aspects related to the optical and acoustic signals, vehicles typology, equipment for emergency response, etc.	Aspects related to the flooding conditions and the water flow
Organizational Aspects	Organizational aspects of the institutional subjects involved in the emergency response	Aspects related to the tunnel manager and operators' experience, communication, emergency plan knowledge, etc.	Aspects related to the rescuers' experience and availability, role identification, communication, etc.
Contextual Features	Resources available in the areas surrounding the accident location	First aid support, viability, etc.	First aid support, viability, etc.

A rigorous mathematical theory, which provides a way for ranking and categorizing multi criteria features, is the Analytical Hierarchy Process, AHP, (Saaty, 2006). The AHP methodology supports the decision-making process and was specifically applied to emergency preparedness to structure alternatives into a weighed multi-criteria framework. The next section presents, describes, and discusses the AHP approach.

3. Ranking of alternatives: the AHP methodology

In the previous section, we outlined the need for a software tool, acting as an emergency preparedness instrument that should be able to address and judge several distinct features of a risk element and its correlated emergency response. In particular, the software tool should assess the importance of so different topics as physical, structural, technical, contextual, and organizational issues. Moreover, it should put together and consider the role played by several actors such as tunnel manager (in case of road tunnel accident), emergency team, civil protection authority, Red Cross, firefighters, prefecture, municipality, and police force.

To put it simple, the problem regards distinct features and distinct actors that are orbiting around the same risk (*e.g.* road tunnel accident, flood risk). The decision maker needs to understand not only qualitatively but also quantitatively the effectiveness of the emergency preparedness structure so to assess its efficiency and to identify some feasible and valuable improvements. The call for a quantitative evaluation is bound to the identification of the most demanding features as well as the most efficient enhancements. A quantitative evaluation of a specific risk allows also tracking dynamically its evolution that is bound to the structure on which it insists and to the emergency preparedness machine. This allows understanding if the structure safety is increasing or at least steady in time. It allows also evaluating the sensitivity of the structure or device to find the most valuable enhancing actions.

The Analytic Hierarchy Process (AHP), developed by Thomas L. Saaty in the 1970s, provides a method for decomposing a complex decision problem into a hierarchy of more easily comprehended sub-problems, which can be worked with and evaluated on their own. The first step is, then, the definition of the hierarchy that is performed with three steps:

1. define the goal of the hierarchy and put it at its the top level;
2. build downward the hierarchy in different levels. Each level has to gather those factors that directly influence the elements of the level just above and that are directly influenced by the elements of the level just below;
3. at the bottom of the hierarchy, place the indexes. These indexes represent the factors that will be considered for judging the analyzed system.

In the evaluation of this hierarchy, the AHP considers measurements and other objective data about its various elements and converts them to numerical values that can be processed, evaluated, and compared over the entire range of the problem.

Furthermore, AHP works with the decision makers' judgments about the meaning and importance of that information, deriving a numerical weight or priority for each element of the hierarchy, allowing the elements to be compared to one another in a direct and consistent way. To derive the weights, the AHP is based on the innate human ability to use information and experience to estimate relative magnitudes through paired comparisons. These comparisons are used to construct ratio scales on a variety of dimensions both tangible and intangible. The AHP thus leads from simple pair-wise comparison judgments to the priorities in the hierarchy. AHP provides a mathematical framework to assess the judgments consistency, *i.e.* to establish that the pair-wise comparisons are not in contrast. The experts have to formulate judgments according to the Saaty scale.

4. Application to case studies

Hierarchy definition

In order to apply the AHP methodology to the evaluation of the emergency preparedness performances, we had to build the hierarchy for categorizing the criteria involved in the decision process. Interviews to tunnel operators and managers (Montagna and Spano, 2006) and the literature and emergency protocol analyses (Caragliano, 2006; Manca *et al.*, 2006) supported the hierarchy identification. A scheme was sketched to assist in collecting data and identifying the aspects to investigate. Different techniques, such as observation, focus groups, case study, and so forth were adopted to integrate the interviews. The main topics discussed in the interviews were the description of in-field operators' activities, of operations performed during a crisis, and the most likely accident scenarios.

This preliminary work led to the development of a four levels hierarchy, even if a different problem would lead to a completely different hierarchy. The four levels hierarchy allowed achieving a good categorization of criteria, without exceeding either

in simplicity or in detail. The macro-criteria of interest are at the higher level of the hierarchy, *i.e.* the criteria that the decision maker will finally take into consideration. At the lower level, the user has to answer to questions (*i.e.* indexes) for the evaluation of the analyzed system. Each index is expressed in terms of a corresponding question.
At the first level of the hierarchy, we identified three main areas of interest: the Physical, Organizational, and Contextual Features reported in Table 1.
The second and third levels of the hierarchy go deeper in detail by analyzing different aspects related to the main topics of previous level (see Table 2, Table 3, and Table 4).

Table 2: Hierarchical tree of the Physical Features

PHYSICAL FEATURES	
ROAD TUNNEL ACCIDENT	
TUNNEL PHYSICAL STRUCTURE • Emergency Exits • Others	FIRE EXTINCTION SYSTEMS • Equipment for the Emergency Tunnel Staff • Others
TRAFFIC MANAGEMENT • Optical Signaling • Vehicles Typology • Others	COMMUNICATION SYSTEMS • Acoustic Signaling • Optical Signaling • Others
STANDARD LIGHTING • Others	DETECTION SYSTEMS • Alarm Type • Others
EMERGENCY LIGHTING SYSTEM • Others	VENTILATION SYSTEM • Others
FLOOD RISK	
SOIL MORPHOLOGY • Water flow formation • Flooding conditions	TECHNICAL DATA • Flooding conditions means availability

Table 3: Hierarchical tree of the Organizational Aspects

Level 1: ORGANIZATIONAL ASPECTS	
ROAD TUNNEL ACCIDENT	
INTERNAL PROTOCOL UPDATING • Tunnel Manager Experience • Emergency Procedure Update	TRAINING • Operators' Experience Emergency Procedure Update
EMERGENCY COMMUNICATION SYSTEM • Operators' Experience • Role and Responsibility Identification • Communication with Tunnel Users • Communication with the Public • Communication with the Mass Media • Communication with External Authorities	EXTERNAL EMERGENCY PLAN • Role and Responsibility Identification • Coordination Procedures • Scenario • List of Resources • Evacuation procedures • Post-intervention procedures • Operators' knowledge • Communication with Tunnel Users

TUNNEL TECHNICAL STAFF ACTIVITY • Others	INFORMATION SYSTEM • Operators' Knowledge
TUNNEL EMERGENCY STAFF • Operators' Availability • Operators' Knowledge • Operators' Experience	INTERNAL EMERGENCY MANAGEMENT • Scenarios • Communication • Emergency Procedure Update
EXTERNAL EMERGENCY MANAGEMENT • Time • Operators' Devices • Role And Responsibility Identification	EMERGENCY COORDINATION TRAINING • Operators' experience
EXTERNAL EMERGENCY PLAN UPDATING • Evacuation procedures	
FLOOD RISK	
FLOODING AREA PREVENTION MANAGEMENT • Procedures	INFORMATION SYSTEM • Rescuers' knowledge
EXTERNAL EMERGENCY PLAN • List of Resources • Coordination Procedures • Role and responsibility identification • Evacuation procedures • Post-intervention procedures • Rescuers' knowledge	EMERGENCY COMMUNICATION SYSTEM • Communication with flooded area Users • Communication with the Public • Communication with the Mass media • Communication with the neighboring countries • Rescuers' experience • Role and responsibility identification
TRAINING • Rescuers' experience	INTERNAL EMERGENCY MANAGEMENT • Emergency Procedure update
EMERGENCY COORDINATION TRAINING • Rescuers' experience	EXTERNAL EMERGENCY PLAN UPDATING • Rescuing procedures
EXTERNAL EMERGENCY MANAGEMENT • Time • Role and responsibility identification • Rescuers' devices	EMERGENCY MANAGEMENT • Scenarios • Communication • Infrastructure availability
FLOOD EMERGENCY STAFF • Role and responsibility identification • Rescuers' availability • Rescuers' experience • Rescuers' knowledge	

The questions are either qualitative or quantitative. Qualitative indexes are questions that assume only a finite number of alternatives (*e.g.* yes/no, low/medium/high). Quantitative indexes are questions referred to measurable variables (*e.g.* length, number of elements, intensity, flowrate).

Table 4: Hierarchical tree of the Contextual features

Level 1: CONTEXTUAL FEATURES	
ROAD TUNNEL ACCIDENT	
PRESENCE OF EXTERNAL RESOURCES • First aid support • Thermo-cameras • External emergency viability • Water resources	EXTERNAL TRAFFIC MANAGEMENT • Viability • Optical signaling systems
EMERGENCY COMMUNICATION SYSTEM • Radio system	
FLOOD RISK	
EXTERNAL TRAFFIC MANAGEMENT • Viability	EMERGENCY COMMUNICATION SYSTEM • Communication system
PRESENCE OF EXTERNAL RESOURCES • First aid support • Water resources	

Pair wise comparisons

Once the hierarchical structure is defined, it is time to evaluate the relative importance of criteria pertaining to the same level (weights evaluation). By doing so, in the evaluation of the final score, expressing the emergency preparedness performance, the most relevant features will give the highest contributes. The pair-wise comparisons of the AHP methodology quantify the relative importance of indexes. This procedure produced the weights of the indexes for each level of the hierarchical structure. Experts, assisted by the material we discussed above (*e.g.* literature, interviews), carried out the pair-wise comparisons.

AHP Outputs

Once the hierarchy is set up and the weights are computed, the emergency preparedness performance Evaluator is ready to be used. The list of people involved in the questionnaire depends on the accidental scenario considered. For instance, in case of tunnel accident, the people that must answer to the questions are the tunnel manager, one person representing the civil protection authority, one person for each civil protection organization. The Evaluator requires that more than a person answer to some specific questions so to consider criteria related to different agencies, their cooperation, coordination, and communication.

When the questionnaire is completed, the AHP evaluates some performance indexes. In particular, we decided to evaluate the following performance indexes:

- an overall performance index, expressing the global performance, from all the points of view (Physical Features, Organizational Aspects, Contextual Features) ;

- three indexes, one for each first level category, expressing the performance of the emergency system in each of these categories. The sum of these values is the overall index;
- three relative scores, measuring the goodness of the system in each specific first level category. These values are different from the previous ones because they are not weighed.

5. Conclusions

In this paper, we presented a computer based Decision Support System, named Evaluator. Such a tool focuses on the evaluation of the civil protection organization in case of accidents in road tunnels. The Evaluator is based on the AHP mathematical framework that provides a way to translate qualitative judgments into values and, consequently, comparing alternatives.

The whole framework is so structured:

1. input data:
   - user answers (quantitative scores);
   - AHP matrices (weights);
2. Evaluator (AHP matrix algebra to determine the performance indexes);
3. output results:
   - the overall performance index;
   - three indexes one for each first level category (their sum is the overall index);
   - three relative scores that measure the goodness of the score obtained for each specific first level category.

The same approach can be adapted to judge different risk typologies.

6. References

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