Flood disaster management with the use of AHP

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1 Introduction

Flooding disasters are a kind of natural hazards that occur with increasing frequency in recent years all around the world (ICSU, 2005) causing extensive damage to infrastructures and often costing the life to a large number of people. Specifically river flooding, apart from adverse weather conditions, may be also attributed to existing and continuing encroachment on flood plains through unplanned development and/or aging of flood protection structures. Under such circumstances, there is an ongoing effort for better ways of protecting human life, land, property and the environment by improved risk management and prevention on the one hand and emergency planning on the other. Risk management and prevention aim at improving the technical and social actions that control and reduce possible damages in case of emergency. These actions are combined to reduce the risk through interventions and behaviours that mitigate hazards and vulnerability before a disaster occurs. Preventive actions are devoted to define the operational procedures that must be followed in a short period of time (emergency planning) and to reduce vulnerability by mitigating hazards as well as by implementing activities in the long period (land use planning). These actions are internationally recognised as part of a unique managerial process, the so-called 'disaster cycle' (Tierney et al., 2001) that illustrates the ongoing management process by which governments, private businesses, and the society try to reduce the impact of either an occurred or a possible dangerous event. This includes mitigation, preparedness, response and recovery as the steps of a multi-disciplinary process.

In case of an emergency caused by an unexpected flooding, a series of civil protection institutions, such as firefighters, local authorities, volunteers, etc., together with non-institutional entities, e.g., residents, are involved in the relief and rescue interventions. Different individual and collective factors can influence the risk situations and the social capability to accept and deal with them (Slovic, 2000; Ntouskas and Polemi, 2012). A gap in the understanding of the crisis exists when an emergency occurs, because of the factors characterising human cognition, social relations, inter-group dynamics, and team building. With reference to flood emergency management, the situation is already difficult in river basins controlled by a single authority, and becomes challenging when dealing with trans-boundary river flooding, which may start in one country of jurisdiction and then propagate downstream to another (Akter and Simonovic, 2005). In this case, the demands on communications, information and data sharing, compatibility of forecasting methodologies, and, eventually close collaboration in disaster flood management are particularly strong and important. It is evident that the decision making process in a flood emergency preparedness constitutes a multi-criteria problem with several alternatives.

The structuring of these alternatives into a multi-criteria framework can be done with several methodologies; to name few, there are PROMETHEE II as described (among others) by Frinka et al. (2011), and the PARETO set as described by Papazoglou et al. (2000). In this work the weighed structure of alternatives was achieved with the support of the analytical hierarchy process (AHP) approach (Saaty, 2007). As will be described in the following, the indices pertaining to the parameters of the problem are categorised, grouped and compared using the principles of AHP.

The proposed methodology was elaborated within the pre-emergencies EC funded project, which aimed at the construction of a tool capable of evaluating in a single measurable index the actual response level of a disaster management system in case of both sudden and mounding risks, such as the flood risk, which is being considered in this paradigm.

In the remainder of the paper the reader can find: the tool development in Section 2 and the case study application in Section 3; the results from the application are presented in Section 4, while the use of the Evaluator is presented in Section 5; lastly, the conclusions of the work are presented in Section 6.

2 Problem setting

2.1 General

The decisions that need to be taken by civil protection authorities, should an accident happen, are swift and usually based on incomplete and ambiguous information about the unfolding event and its location (Paton and Flin, 1999). On the other hand, the mobilisation of multiple stakeholders is a non-trivial task. In that sense, the use of an emergency management system that can control the possible dangerous effects of the accident by supporting the emergency staff against high stress components is indispensable. Plans should be based on a detailed and comprehensive analysis of operational demands and connected actions, by organising the multidisciplinary competences, while sharing the available means and human resources. To facilitate the development of emergency response systems assisting performance during a crisis, organisational and inter-organisational coordination must be improved, by focusing on both internal and external vulnerability elements for each organisation. This includes the proper definition of emergency preparedness activities, such as the areas of responsibilities, the roles of participating bodies and the available means to be shared. Good knowledge of the accident scene both regarding the geomorphology of the site and the population distribution is also indispensable. In this perspective, software tools, as mentioned by Yeralan et al. (2011), can be of paramount importance in supporting the actors to consider the multifaceted factors characterising the emergency response. Additionally, the implementation of most multi-criteria decision aid methods requires fixing of certain parameters in order to model the decision-maker's preferences (Frinka et al., 2011). To this end, a dedicated tool was developed within the pre-emergencies project under the code name 'Evaluator' aimed at being used as a technical instrument to simulate the overlapping assets of a multi-actor civil protection group. This was done by analysing a series of parameters that pertain to the:

- physical area of the accident, such as the characteristics of the flooded region
- organisational area, such as the organisational aspects of the institutional groups involved in the emergency response
- contextual area, such as the resources available in places surrounding the accident location.

2.2 The setting of the emergency response as a multi-criteria problem

As described above, the software tool acting as an emergency preparedness instrument should be able to address and judge several distinct features of risk element and the correlated emergency response. To be clearer, if one concentrates on the flooding risk, one would like to assess the importance of different topics such as, the geomorphology of the area, the population density, the organisational characteristics of civil protection authorities, etc. Moreover, one would like to understand not only qualitatively, but also quantitatively, the effectiveness of the emergency preparedness structure so as to assess its efficiency and to identify some valuable and also feasible 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 of its dynamic evolution that is closely related to the emergency response. This allows the understanding of the structure safety, namely, whether it is increasing or it stays rather steady in time. It allows also assessing the structure sensitivity so as to find the most valuable enhancing actions.

All these topics are connected to the decision-making and priority theory. One should acknowledge the analysts' need for measuring and assigning numbers to judgments. It is also necessary to combine measurements in order to understand the complex environment and to make the right choices in a decision-making procedure.

A further step is the recognition of the need for a multi-criteria logic that provides different and often better answers to the aforementioned issues than the one-dimensional (ordinary) logic.

To take a decision one needs various kinds of knowledge, information and technical data, namely details about the problem to be decided, such as:

- the actors involved in the problem
- their objectives and policies
- the parameters affecting the outcomes
- the time horizon, scenarios and constraints that pertain to the problem.

According to Saaty (2007), the decision-making activity can be seen as a process that involves the following steps:

1 structuring a problem as a hierarchy or as a system with dependency loops

2 elicitation of judgments that reflect ideas, feelings and emotions

3 representation of these judgments with meaningful numbers

4 using these numbers to calculate priorities of the elements of the hierarchy

5 synthesis of the previous results to determine an overall outcome

6 sensitivity analysis of the changes that induce to decision.

2.3 The analytic hierarchy process as a tool for decision making

The AHP converts those judgments to numerical values that can be processed, evaluated and compared over the whole range of the problem. At the end, a numerical weight or priority is derived for each element of the hierarchy, allowing the elements to be mutually compared in a direct and consistent way. AHP is a problem-solving framework of logic that spans the spectrum from instant awareness to fully integrated consciousness by organising perceptions, feelings, judgments and memories into a hierarchy of forces that influence decision results. The AHP is based on the innate human ability to use information and experience to estimate relative magnitudes through pair-wise comparisons. These comparisons are used to construct relative scales on a variety of dimensions both tangible and intangible. The AHP thus leads from simple pair-wise comparisons to the priorities in the hierarchy. The linguistic and subjective evaluations that take place in a questionnaire should have their own numerical value in a predefined scale. In classical AHP these numerical values are exact numbers, however, certain analysts (Singh et al., 2012) believe that linguistic values can change from person to person and belong to an interval with a most likely value; consequently they use the 'fuzzy AHP method' taking the fuzziness in to account to provide results that are not prone to risks.

By directly collaborating to the construction of the hierarchy, the AHP approach allows the involved actors to become committed participants, who fully understand, appreciate, and weigh the influences of the features that control the outcome. In order to apply the AHP methodology to the evaluation of the emergency response performances, the hierarchy for categorising the criteria involved in the decision process was analysed, discussed and proposed. This categorisation has led to several hierarchical layers according to the case-study examined and the level of detail pursued. 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, while at the lower level there are the questions to reply for evaluating the response system under consideration, as described in the following.

3 Structuring the flooding accident case-study

3.1 General setting

This section presents and discusses the profitable application of the AHP methodology to a selected case study. It comprises the evaluation of the emergency response performance in case of the flooding (Montz and Gruntfest, 2002) of a greater area owing to the excess effluent waters of a river in Northern Greece (Nivolianitou et al., 2007), where the coordination among three nations is needed, as this river is a tri-national one.

In order to apply the AHP methodology, the hierarchy for categorising the criteria involved in the decision process was analysed, discussed and proposed through the interviews (Montagna and Spano, 2006) that have been held with the officials of the civil protection in the area. The parameters chosen stem from the list reported in Section 2.2. Additionally, emergency protocol analysis and literature review were also deployed to identify key-parameters. A scheme was sketched to assist in collecting data and in identifying the aspects to investigate. The main topics discussed in the interviews were the description of the 'on-scene' operating groups during the crisis and of the most likely accident scenarios.

This preliminary work has led the analysts to the development of a four-level hierarchy for the specific case-study, by which a good categorisation of criteria was achieved, without exceeding either in simplicity or in detail; it is worth noting that different flooding scenarios can lead to a different structure of the hierarchy. At the first level of the hierarchy, we identified three main areas of interest, involving physical, organisational and contextual criteria. Table 1 describes each of these categories.

Table 1 Description of the first level of the hierarchy for the physical features

Level 1	*Description*
Physical features	Related to the technical and physical aspects of risk in a flooded area (i.e., soil morphology, dikes, dams, alternative routings).
Organisational aspects	Related to the organisational factors of inter-organisation coordination and communication.
Contextual features	Related to external artificial and natural 'structures' (i.e., retentions measures, helipads, medical services, emergency communication system).

The second and third levels of the hierarchy go deeper in detail by analysing different aspects related to the main topics of each previous level. As far as the physical features are concerned, the second level of the hierarchy takes into consideration factors about the flooded area, physical structure and soil morphology, the measuring/signalling system and the announcement/notification systems. Further on in detail, the third level of the same parameter considers issues related to water flow formation, the flooding conditions and the means availability. Table 2 reports the complete characterisation of the branches of the hierarchical tree related to physical features.

Table 2 Description of the second and third level of the hierarchical tree for the physical features

Level 2	*Level 3*
Flooded area physical structure	• Flooding conditions
	• Means availability
Soil morphology	• Water flooding information
	• Flooding conditions

Analogously, organisational aspects relate to the emergency protocol updating, the emergency communication and information systems (especially among the neighbouring countries) and the participating actors training for emergency response. The third level of the same parameter involves the analysis of rescuers' experience, the communication with the flooded area inhabitants, with the public, with the mass media, with external authorities and with the neighbouring countries. It deals also with the use and updating of procedures, with the profile specification of competent authorities and the identification of roles among the intervening group.

Similarly, the contextual features in the second level of the hierarchy take into account the presence of additional resources, the parallel traffic management in the flooded area and the emergency communication system established. Within these features, the first aid support, the water resources that may aggravate the situation, the viability and the communication system are the features considered in the third level.

All these features are investigated through specific sets of questions asked at the fourth level, as the ones presented in Figure 1, that permit the elicitation of information needed. These questions are identified by univocal serial numbers directly related with the parameter and level of analysis associated.

Figure 1 An Excel snapshot with the indexes and their pair-wise comparison at level 4

Level 1 **OGRANIZATIONAL**
Level 2 EXTERNAL EMERGENCY PLAN
Level 3 Coordination Procedures
Level 4

5010	Presence of the flooded area map in the external emergency plan
5020	Are there safety installations/equipment marked on the map in the flooded area?
5030	Indication of the flooded area physical features in the emergency plan
5050	Presence of a flooded area map in the safe places
5060	Is there a periodic checking of safety equipment in the safe places?
5070	Are voluntary organizations invited by competent authorities to participate in the crisis?

	5010	5020	5030	5050	5060	5070
5010	1	3	5	3	1	3
5020	1/3	1	5	1/3	3	3
5030	1/5	1/5	1	1/3	1/3	1/3
5050	1/3	3	3	1	1	1
5060	1	1/3	3	1	1	1
5070	1/3	1/3	3	1	1	1

As far as the question typology is concerned, the latter distinguishes among qualitative and quantitative indices, namely

a questions that either do not assume any numerical values or that can be attributed a finite number of choices (yes/no, low/medium/high, etc.)

b questions that assume a numerical value (length, number of elements, etc.).

In the present case study the analysts have attributed three elements at level 1, 15 elements at level 2 and 40 eight elements at level 3. The number of questions at level 4 depends significantly on the branching structure of the proposed hierarchy; so, in this study there is a maximum of a 30 questions belonging to the physical branch, at least 78 belonging to the organisational branch and 75 questions related to the contextual branch. It is worth noting that not all the branches or questions are equally active, as some terminate prematurely not leading to a deeper level of detail, if a query gets a negative response. After the completion of the questionnaire, the AHP methodology evaluates some performance indexes, as will be described in the following.

4 Calculations

The definition of the hierarchical structure is followed by the evaluation of the relative importance of the criteria pertaining to the same level (weights evaluation). By doing so, in the evaluation of the final score and by expressing the emergency response performance, the most relevant features will give the highest contributions. The relative importance of indexes was quantified by pair-wise comparisons through the AHP methodology as described by Saaty (2007). Namely, the experts were asked to judge, for instance, the relative importance of physical against organisational criterion. The judgment made by experts is based on a qualitative assessment of the relative importance of couples of criteria. When the qualitative assessment is presented, discussed and shared among all the stakeholders, it is simply transformed in a quantitative assessment by using a correspondence scale from 1 to 9 (Manca and Brambilla, 2011). From these comparisons the physical and organisational areas resulted to be more relevant than the contextual one. This type of analysis was repeated for each branch of the hierarchy to weigh the different criteria involved in the final judgment. The pair-wise comparisons were carried out by experts, assisted by the material and documents that have been discussed above (i.e., literature, interviews, etc.). For example, at the first level of the hierarchy: physical, organisational and contextual criteria were compared starting with the relative importance of:

- physical against organisational criteria
- physical against contextual criteria
- organisational against contextual criteria.

This type of analysis was repeated for each branch or the hierarchy to weigh the different criteria involved in the final judgment.

However, not all the features or actors have the same relevance in determining the performance of the emergency response. To that end, a number of indices pertaining to the parameters described above (on four sub-layers of detail), were identified and categorised through the grouping of similar characteristics, so as to compare features related to the same areas. This categorisation, grouping and comparison made according to the AHP principles allow the discarding of the least important features by singling out a weighed scale of indices. In that sense, the AHP approach supports decision-making in emergency preparedness through alternatives structured into a weighed multi-criteria framework.

Once the hierarchy is setup and the weights determined, the emergency performance Evaluator is ready to be used. In particular, the analysts decided to evaluate some additional performance indexes, namely:

- An overall performance index, expressing the global performance, from all the points of view.
- 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.

The first item of the above list, 'overall performance index', expresses the global performance of the emergency response. The considered system in the present case study, in a normalised scale from zero to one hundred, gains a score of 73 points. In detail, 32 points come from the physical area, 30 from the organisational area and 11 from the contextual area. These last three values do not allow understanding of the performance of the analysed system in each field. Hence, the analysts proposed three additional marks about the not weighed score of the system in each area. For the examined case, the emergency response is very good regarding the physical area (score of 95%), whilst it is sufficiently good in the organisational area (score of 65%). Conversely, the emergency response is quite weak in the contextual area (the score is only 10%). This means that, even if the performance in physical related criterion is quite high, it contributes to the overall index in the measure of only 32 points.

Moreover, an increase of the physical score by adopting some additional effective safety equipment will not affect significantly the final score of the considered emergency response. On the other hand, an improvement in the Organisational area will probably lead to a more significant increase of the final score, because the analysed system is quite far from the optimum (65% against maximum theoretical value of 100% for that specific field of investigation and possible improvement).

The whole framework is then constituted by:

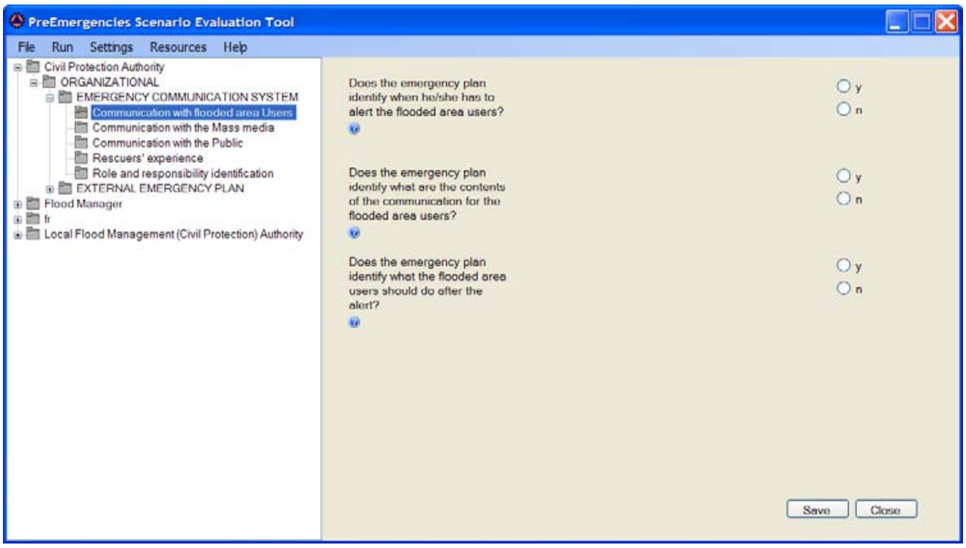
- the input data
  - user answers (quantitative scores)
  - AHP matrices (weights)
  - The Evaluator (AHP matrix algebra to determine the performance indexes)
- The output results
  - the overall performance index
  - three indexes one for each first level category (their sum is the overall index)
 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

5 The use of the Evaluator

The pre-emergencies team developed a user-friendly interface (see Figure 2) for the final users that allows performing the emergency response analysis. The user can load an accident scenario (e.g., a flooding episode), answer the questions related to the macro-areas of interest (physical and/or organisational and/or contextual), and run the Evaluator engine to assess the performance of the emergency response. It is evident that, as the participating stakeholders in an emergency response scheme are multiple and equally multiple may be the users that simultaneously and independently run a scenario in order to evaluate a response scheme, e.g., the chief of the civil protection troupes together with the head of communications and the mayor of the flooded area. Their answers are needed in order to rate their cooperation, coordination and communication degree.

When the questionnaire is completed, the Evaluator calculates the performance indices mentioned in Section 4, namely the overall performance index, the three indices, one for each first level category and three relative scores. The indices take values from one to one hundred. The software is useful for either performing a sensitivity analysis or monitoring the risk management dynamics. The former is achieved by multiple runs of the Evaluator changing each time one or more input data to understand the dependency of the output data from each input so as to optimise the investments/actions. Monitoring of risk management dynamics is achieved by running the Evaluator at predefined time intervals to track the dynamic evolution of the system according to the modifications introduced by competent authorities. According also to the *distance* of single performance indexes from the optimal values (i.e., 100% optimality), it is possible to identify and define a priority scale for possible modifications, improvements, interventions on the emergency-response machine. This point allows also allocating resources on specific areas that are weaker than other ones and therefore are also more promising for significant improvements and stabilising actions (Manca et al., 2008).

Figure 2 A snapshot of the Evaluator GUI (see online version for colours)



6 Conclusions

The paper focused on the development of a decision-making tool for emergency planning and response specifically adapted to flood accidents. The proposed tool is a simulator (i.e., a computer based software tool) capable of identifying possible lacks within the 'emergency machine', while allowing for further improvement of specific areas of the emergency system, such as technical equipment, human factors, protocols, response time and sequence of events in both a pro-active and dynamic way.

The AHP methodology has been adopted to deal with the hierarchic structure and to determine the relative weights among the single features; thus, it distinguishes itself from other decision-making techniques by its capability to not only allow the decision to be considered more ‘objective’, but also by encouraging communication that leads to a better global understanding of the problem and its possible solutions.

It should be noticed here that the application presented is somehow outside the ‘mainstream’ application of AHP, i.e., the latter is not applied to a decision problem (e.g., selecting the best management system), but rather to the quality evaluation of a given system. Consequently, an important result of the analysis is not only the overall score of the system, but also the relative contributions of the different parts of the hierarchy, which allow the analysts to identify specific needs for improvement in certain dimensions of their modelling.

Following the straightforward application of AHP in this case study, interested practitioners of the multi-criteria-decision-making (MCDM) community could consider the fact that the AHP can be used not only for decision making but also to provide a structured framework for quality evaluation, an issue of AHP that has not become that evident in literature so far. This compensated the fact that in cases of no peculiar difficulties in system modelling needed to be solved (as in the present case study), AHP could be used to evaluate and consequently improve system performance.

Additionally, the AHP was opted as the best suited method for this problem owing to the important *advantages* that the former presents, namely:

a the use of a subjective scale and of an efficient communication system among analysts and emergency planning practitioners, using simple connotations to describe phenomena

b the pair-wise comparison technique used by AHP, which is usually much easier for the interviewee, as the latter compares two items at a time than many items all at once

c the possibility to use both qualitative and quantitative indices in the same framework.

Some *disadvantages* of AHP also in this particular problem, remain:

a the inconsistency in judgment that may appear in different levels of the hierarchy, which, however could be faced by the estimation of the so-called inconsistency index for each comparison matrix

b the subjective scale that is vulnerable to human psychology

c the number of comparison tables that can become very large, if one uses a lot of comparison attributes, strengthening the tendency to exclude valid comparison attributes in order to keep the number of calculations manageable.

The AHP methodology, similarly to some other MCDM methods, shares the positive feature of the active involvement of many decision actors responsible for the emergency preparedness; this leads to the active discussion and assessment of procedures to determine the relative importance among different and often incommensurable issues. By doing so, the final result is a shared vision of the problem and the quantitative results produced by the Evaluator are no more seen as external computations produced by some aprioristic software tool. The training in the use of the Evaluator software can be done by risk analysts to decision makers so as to make its structure and operating mode well known. Additionally, its results become accepted and shared and can be validated by all of the main actors, who play different roles within the multifaceted machine of the emergency planning and response. This allows for the preparedness of the ‘emergency machine’ should an incident occur.

As an epilogue, one could say that MCDM methods, including the AHP, try to bring rational thinking to complex decision problems; an analyst should use the analytic hierarchy process as just one component of the overall quality evaluation, as it can be a valuable supplement to other objective and subjective techniques that measure system or product quality.

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