On the Assessment of Disaster Management Strategies

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ABSTRACT

Decision support systems can recommend strategies for disaster management, which can be further discussed by decision-makers. To provide rationales for the recommendations, the strategies need to be assessed according to relevant criteria. If several strategies are available, the criteria can be used for ranking the strategies. This paper addresses the issue concerning the choice of suitable criteria from several perspectives. The assessment integrates concepts on robustness, experience with regard to the implementation of a strategy, quantifiable ratios which can be deduced from simulations, and system-specific parameters. Objectives are to facilitate transparency with respect to the assessments, to provide a basis for discussions concerning the strategies, and to preserve adaptability and flexibility to account for the variability of disasters and users' preferences. The assessment should be used for ranking solutions gained from a case-based reasoning system and to reveal contributions of criteria values to the overall assessment.

Keywords

Multi-criteria assessment of disaster management strategies, ranking of case-based reasoning solutions

INTRODUCTION

Decision-making in disaster management (DM) can be supported by IT-based recommendations of strategies. These recommendations need information on the achievement of defined objectives and on how they are derived. If several strategies are available, a ranking facilitates decision-making. This paper addresses the assessment of strategies from different perspectives and integrates several approaches, which are important in respect to decision-making in DM taking into account decision-makers' preferences and the variability concerning issues arising for different events. First, available knowledge on how the strategy worked in the past is used. Second, the robustness of solutions is considered. Third, system-specific parameters which depend on the underlying decision support system (DSS) are included indicating to which degree the user can trust the solutions recommended. Forth, current constraints such as resources or time pressure are regarded by running simulations of possibly suitable strategies. The assessment proposed is part of a case-based reasoning (CBR) (e.g. Aamodt and Plaza, 1994) system to be developed for recommending DM strategies. It should be applied after adapting retrieved solutions to the current situation and before revising the suggested solution. This research is motivated by the fact that the solution of the most similar case does not have to be the best one for the current problem, since successful and less successful solutions should be stored in the case base. Further, the assumption that similar problems have similar solutions can be limited, amongst others, by the inability of a similarity measure to capture the usefulness of a case for a current problem or identify the relevance of a feature in solving a problem or the absence of relevant features (Kar, Chakraborti, and Ravindran, 2012). The assessment complements the case-based approach by evaluating each alternative in a quantitative manner to establish a broader discussion basis and support the understanding and trust in the recommended solutions. The theoretical propositions in this paper are studied on general DM but the main focus is on the response phase. The practicability of the approach and visual support for the decision-makers is of high importance.

This paper is organized as follows: First, strategy assessment in DM will be discussed. Second, the framework for the assessment will be presented and depicted by a use case. After a short overview of related work, the paper will be concluded with a discussion on the results and future work.

STRATEGY ASSESSMENT IN DISASTER MANAGEMENT

Rongier, Lauras, Galasso, and Gourc (2012) proposed a method to design a crisis performance measurement system and present dimensions of performance (relevance, efficiency, satisfaction, expectation, impact and agility), which have to be aligned with the specific situation by corresponding indicators. The authors focused on humanitarian applications as well as Beamon and Balcik (2008) who make use of performance measurements of commercial supply chains. Divided into resource, output, and flexibility, different metrics such as costs, response time or types of supplies are presented. Several approaches concentrate on one specific aspect to evaluate measures and support decision-making, such as the effectiveness of a strategy in the frame of earthquake mitigation measures (Gupta and Shah, 1998) using loss and response parameters or to evaluate emergency response operations in command and control (Brown and Robinson, 2005) taking into account human and property loss in conjunction with time after initializing response efforts. Hild, Ott, Fischer, and Glökler (2010) provide cost-optimal response actions. Moellmann, Braun, Engelmann, and Raskob (2011) support planning by calculating the duration and required resources of relief measures by means of key performance indicators. Another important concept is the robustness of decisions on strategies, since several options are possible on how the event evolves or how environment changes. The objective is to select a strategy, which performs sufficiently well for many different scenarios (Comes, Hiete, Wijngaards, and Schultmann, 2010). The aim of the response phase is to minimize human and property losses and the recommended measures of the DSS to be developed are based on experiences. Therefore, the success of past measures (which can be stored in terms of physical and social damage), can provide an additional support for decision-making. Furthermore, it is important to preserve the transparency pertaining to the calculation of solutions. A confidence value reflects the accuracy of a CBR solution and besides the similarity values of the retrieved cases, the number of similar cases, the deviation in the solutions of the retrieved cases, the percentage of cases retrieved suggesting a specific solution or the span of the solutions could be taken into account (Cheetham, 2000). To evaluate strategies in disaster and emergency management, multi-criteria decision analysis (MCDA) (see e.g. Belton and Stewart (2002)) methods are applied such as for flood risk management (e.g. Hansson, Larsson, Danielson, and Ekenberg, 2011), nuclear remediation management (Geldermann, Bertsch, Treitz, French, Papamichail, and Hämäläinen, 2007) or evacuation decisions (Kailiponi, 2010). MCDA takes into account multiple goals (decision criteria) in an analytical and transparent manner and is promising in the frame of this paper to integrate the different concepts discussed. In particular, multi-attribute value theory (MAVT) can be used since the solution space is discrete and the data is deterministic. Further, it is assumed that the user is aware of his/her preferences and weights can be assigned directly.

MULTI-CRITERIA ASSESSMENT OF DISASTER MANAGEMENT STRATEGIES

To determine meaningful criteria to judge the suitability of strategies, the idea is to integrate the presented approaches from literature with experience on the success of implemented measures combined with system-specific parameters. The first step of an MAVT analysis consists in problem structuring. The overall goal is to identify the strategy, which poses the best response to the current event. The sub-objectives 'old assessment', 'robustness', 'quantifiable ratios', and 'confidence' are proposed as criteria to characterize the overall objective. These criteria are made measurable through attributes. Figure 1 illustrates the attribute tree with an additional level of parameters used to calculate attribute values. The suggestions on the strategies are based on experience. One sub-objective is dedicated to the success or effectiveness of past strategies (old assessment), which is made measurable by physical and social damage relative to the intensity of a disaster. The sub-objective 'robustness' considers uncertainties with regard to the extent of a disaster, changing environmental conditions, or insufficient information and corresponds to the agility and impact (in respect of future developments) of measures. Inspired by DSSs in the industrial field, the assessment of robustness of a plan (see e.g. Scholl, 2001) can be applied by determining the average utility and probability to achieve a minimal value by implementing a strategy under a scenario. The average utility can be calculated through the extent of damage relative to the intensity of the disaster (see old assessments). The better the strategy, the smaller the relative damage. When a value for the minimal utility is set, the probability to achieve that value can be calculated. A further criterion is 'quantifiable ratios' and the corresponding attributes are 'response time' and 'resource utilization', which refer to the agility and efficiency of measures. Concurrent activities can lead to delays during the implementation of a strategy and possibly result in additional fatalities and property damage. The value for the resource utilization reveals idle times and possibilities to adapt the distribution of resources or sequence of activities. The idea is to conduct a simulation-based performance analysis. The duration to implement a measure can be modeled by a probability distribution to account for the uncertainty concerning resources available or the number of e.g. evacuees, which has an effect on the duration of a strategy. In addition to old assessments, a new approach in this context is to consider system-specific parameter as well by defining 'confidence' as a further sub-objective where the similarities between the solutions retrieved can be integrated. The more strategies with similar actions are

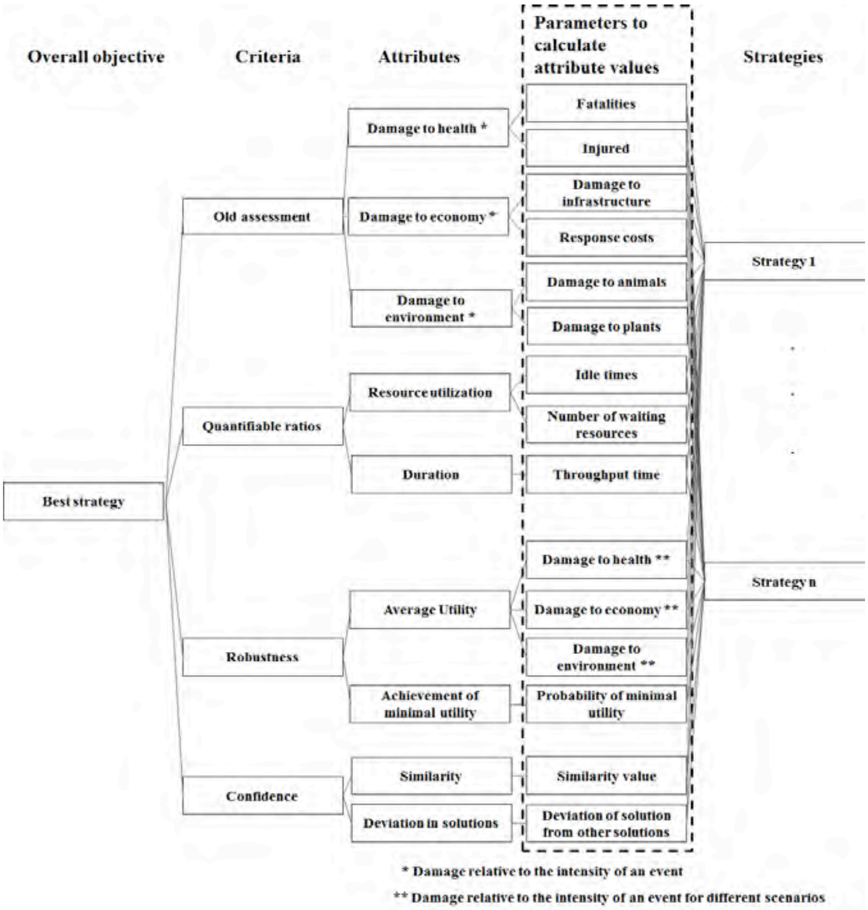

Figure 1. Attribute tree and possible parameters to calculate the attribute values.

identified, the higher the confidence in the solution proposed.

To make the different strategies comparable with respect to several attributes, value functions $v_1,\ldots,v_9$ have to be defined mapping each measured value x_{ij} of attribute i for alternative j to the same interval [0,1]: $v_i(x_{ij})= (x_{ij}-W_i)/(B_i-W_i)$, $i=1,\ldots,9$ where W_i denotes the worst case value for attribute i and B_i the best case value, respectively, which can be set individually to handle the variability of disaster events. The aggregation by a weighted sum is commonly used and easy to understand. The assumption is that the attributes are independent. Concerning the damage attributes, an overlap may be possible but is not always the case. The higher the damage to health, the higher are the response costs and therefore the economic damage. However, complex response increases costs and do not necessarily depend on the number of injured. Therefore, both attributes need to be preserved, also because the focus is to give the decision-maker the possibility to trade-off between different types of damage. Resource utilization depends on the idle times and relates to the duration of the whole strategy. Again, the purpose is to facilitate the determination of individual importance levels for attributes, which also means to indicate possible dependencies and openly discuss them. Information on success and duration of past implemented strategies have to be stored in the 'retain' step of the CBR cycle to be used for multi-criteria assessment and to preserve the learning nature of this methodology. The following use case emphasizes the practicability of the approach proposed. All parameters and weights are fictitious, but can be e.g. estimated by experts. The example is deliberately kept simple, also with regard to the scale of the event.

USE CASE

Let us assume a release of a chemical substance. 300 people are endangered and two strategies are retrieved. The first strategy (A) suggests, after giving alarm, to ask the inhabitants in the surrounding area to close their doors and windows. Meanwhile, a water curtain should be established. The second strategy (B) suggests an evacuation instead of closing doors and windows. For the duration of the emergency measures a normal distribution is assumed with following μ and σ^2 (parameters should be regarded as time steps without a unit): 'give alarm' (2, 0.11), 'order to close doors and windows' (4, 0.44), and 'water curtain' (8.33, 2.78), 'evacuation' (13, 9). Strategy A needs 30 units, which are divided into two groups. Strategy B needs 50 units: 40 units for evacuation and ten units to establish the water curtain. Both strategies are modeled with CPN Tools and simulated 1000 times to determine the quantifiable ratios. The values for 'robustness' are generated with two scenarios: long release with first high and second medium/low contamination. It is assumed that both strategies are feasible. For each scenario possible damage to health, damage to economy, and damage to environment, relative to the intensity of the event, are estimated. These values are normalized and aggregated. The average value of both scenarios leads to the average utility of each strategy. Afterwards, a minimal value is set to determine the probability to achieve this value. Due to the estimated long release, sheltering is regarded as less adequate than the evacuation. Table 1 indicates the attribute values and weights. Figure 2 illustrates the result. Strategy B is identified as better with regard to the overall objective. Sensitivity analyses show the solutions' stability with regard to changes in the attribute weights, which may result in a change in ranking.

	Damage to health (old)	Damage to economy (old)	Damage to environment (old)	Scale of event	Duration (in terms of delay)	Resource utilization	Average utility	Achievement of minimal utility	Similarity (confidence)
Strategy A	25	100000	20000	2	14.26	85	50.3	0	95
Strategy B	5	300000	20000	3	20.09	95	66.8	1	55.5
Value range/unit	Number of injured	Euro	Euro	Scales 1-5 (see TSO)	Time steps	Percent	Percent	[0,1]	Percent
Weights	0.27	0.13	0.05	---	0.06	0.02	0.12	0.18	0.17

Table 1. Attribute values for the strategies which are retrieved from the CBR system.

RELATED WORK

Several approaches combine CBR and MCDA such as for stock analysis in the financial market (Shushmita and Chaudhury, 2007), and for ranking alternatives (before adaptation) in the frame of tropical cyclone forecasting (San Pedro and Burstein, 2003). MCDA (ELECTRE) is also applied in the retrieval phase of CBR (Armaghan and Renaud, 2012) or CBR is used for preference elicitation in MCDA (e.g. Chen, Kilgour, and Hipel, 2011). This paper presents a more generic approach and identifies further sensible criteria such as experience on implemented strategies and DSS-specific parameters.

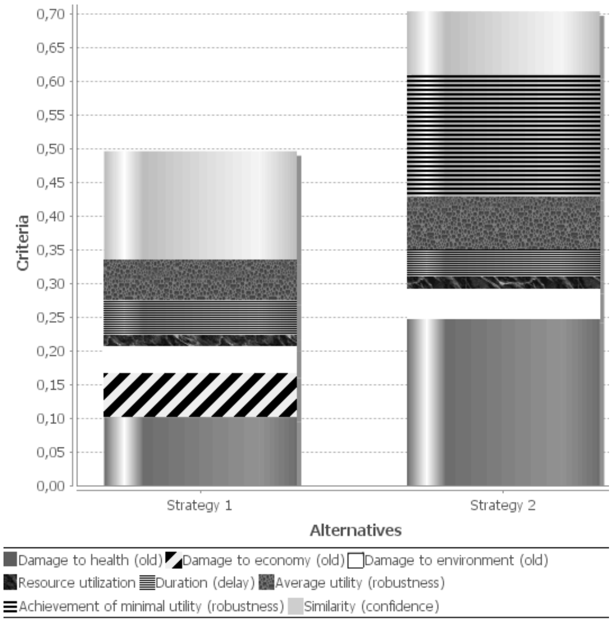

Figure 2. Resulting stacked bar chart.

DISCUSSION AND FUTURE WORK

This paper presents a multi-perspective approach for the assessment of DM strategies by combining important concepts on decision-making in DM in a new manner. The purpose is to provide a ranking approach if several strategies obtained from a CBR system are available, to reveal contributions of criteria values on the overall assessment, and to provide a discussion basis for the decision-maker. Considerations with regard to future developments are taken into account by integrating concepts on robustness. This step needs preparations in advance to be implemented during response. Further, old assessments, which take a retrospective position, are integrated by means of damage relative to the scale of the event. The ratios gained from simulations account for current constraints and uncertainties with regard to time and resources. The strategies need to be modeled in advance and the parameters, such as the number of units or estimates of duration times, can be assimilated, if necessary. Decision-makers' trust and understanding in the mechanism of the DSS are facilitated by integrating confidence values into the multi-criteria assessment. Weights can either be set when needed (the choice of weights is a separate research subject), or default values (for example determined by experts) are set as a starting point and can be changed by the user. The MCDA approach facilitates adaptations at run-time with regard to users' preferences, integration of additional criteria or parameters for the calculation of attribute values, which also depend on the data available. The flexible adaptation of attribute weights account for differences between events and multiple perspectives that need to be integrated. The approach can be generalized by using values on solutions' accuracy or trustworthiness of systems using other methodologies than CBR. If the solutions are not based on experience, the criteria 'old assessment' could be omitted. Further research will be conducted on additional criteria, attributes, the calculation of attribute values, and the normalization functions. The CBR system under development is combined with an MCDA tool to also support the decision-maker in a visual manner whereas the implementation is not completely realized and will also be part of future work.

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