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Analyzing evacuation decisions using multi-attribute utility theory (MAUT)

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Abstract

Emergency managers are faced with critical evacuation decisions. These decisions must balance conflicting objectives as well as high levels of uncertainty. Multi-Attribute Utility Theory (MAUT) provides a framework through which objective trade-offs can be analyzed to make optimal evacuation decisions. This paper is the result of data gathered during the European Commission Project, Evacuation Responsiveness by Government Organizations (ERGO) and outlines a preliminary decision model for the evacuation decision. The illustrative model identifies levels of risk at which point evacuation actions should be taken by emergency managers in a storm surge scenario with forecasts at 12 and 9 hour intervals. The results illustrate how differences in forecast precision affect the optimal evacuation decision. Additional uses for this decision model are also discussed along with improvements to the model through future ERGO data-gathering.

Keywords: Multi-attribute utility theory; risk, emergency management, evacuation.

1. Introduction

Emergency managers can be faced with critical evacuation decisions in times of uncertain risk. The EU-funded project Evacuation Responsiveness by Government Organizations (ERGO) (www.ergo-aston.eu) will create a toolkit of preparedness models for evacuation. These models aim to aid emergency managers and/or policy makers who face the prospect of evacuating a population in response to (or in advance of) a catastrophic incident. Often such evacuation decisions must balance complex objectives and uncertainty concerning key factors. Multi-Attribute Utility Theory (MAUT) can help in these situations by creating a decision model through the elicitation process of expert practitioner [1], [2]. The MAUT process provides a framework through which multiple objectives and uncertainty can be combined to aid emergency managers in making decisions.

A precautionary evacuation decision exhibits multiple, conflicting objectives and high levels of uncertainty. Precautionary evacuation orders can be vital in minimizing the effect of natural or man-made disaster. At the same time emergency managers must weigh the possibility of costly false evacuations and complex human behaviour. As part of the ERGO project eighty interviews totalling approximately 100 hours and 2 workshops were done to identify the objectives of decision-makers during emergency situations. The elicitation process further aligned the preliminary model to be consistent with the managers' expressed decision-making process during evacuation situations [3], [4]. This allows them to better understand the complexity of the situation and critically assess the

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possible outcomes given their objectives. This qualitative analysis also reinforces within the participating stakeholders the view that it is their own values that are being considered. The ERGO project places great emphasis on the creation of preparation tools for evacuation in which the participating emergency managers have high confidence [5], [6].

The preliminary results of this paper are based on eight country site visits to European Union participating countries (U.K., Spain, Germany, Sweden, Belgium, Denmark and Iceland) and Japan. These initial visits were used to create a value hierarchy and an objective function appropriate for each particular countries situation [7]. Further information was collected from two MAUT decision workshops with members of the ERGO Advisory Board. These meetings verified the objectives gathered during the initial visits and also identified the relationship between those objectives and uncertainties pertaining to the hazardous event. Additional interviews were performed with select experts to verify the preliminary model was indicative of objectives and uncertainties that emergency managers face during possible evacuation scenarios [8].

One goal of the MAUT process is to provide decision analysis tools to emergency managers in preparation for precautionary evacuation. One vital question asked by emergency managers in participating countries was concerning the acceptable levels of risk that they should accept before evacuation actions are necessary. The use of the MAUT process answers this question in two ways. First it explicitly analyzes the objectives and uncertainties that various stakeholders must weigh during the evacuation decision. Second, it provides a quantitative analysis of the trade-offs between these objectives. These two components can then be used to optimize outcomes given uncertainty. Section two of this paper will provide an overview of MAUT process and a literature review of the use of decision models in emergency management. Section three will describe the objective elicitation process that was used in creating the decision model. Section four will provide an illustrative example of this analysis including the method of elicitation for both the utility and probability functions. Section five will discuss the results of the model. This discussion will primarily use sensitivity analysis to understand how variation in the parameters can change the optimal evacuation decision taken by emergency managers. Section six will provide additional uses for the decision model. Section seven presents a summary and scope for improvement.

2. MAUT Process & Emergency Management Study

Multi-attribute utility theory attempts to identify relevant objectives for any given decision. Where a decision is typified by multiple objectives it can be difficult to quantitatively compare these objectives one against another. In order to provide insight into this problem a utility function is assessed for each of the relevant objectives. This allows for an appropriate multiple-objective utility function that is then used to identify trade-offs and compare the various objectives in a consistent manner. The basis of utility theory and its underlying quantitative axioms were initially established by von Neumann & Morgenstern [9]. This early work established a normative decision theory that focused on the way that individuals *should* make decisions. Further study and refinement of utility assessments were later added to establish the quantitative foundations of objective function creation [10], [11], [12].

The establishment of these normative decision theories takes a more pragmatic turn through the MAUT process. MAUT methods use similar utility maximization in order to determine *normative* action yet the primary difference is the use of subjective utility gathered through an elicitation process. The importance of the qualitative portion of MAUT cannot be underestimated as it is during this stage that normative axioms are verified and utility functions assessed. This process is especially relevant where substantial historical data is not available or where multiple, competing attributes must be considered. MAUT theories are used extensively in policy analysis and health services where decisions are sensitive to not only economic costs but also more subjective goals such as quality-of-life or environmental concerns [13], [14], [15]. The functional form and necessary axioms for the utility function remain the same between traditional normative theories and MAUT. The primary difference is the flexibility given the researcher in modelling the utility function [16].

Using a prescriptive process an analyst is able to take a very direct approach to structuring the decision process of the DM and is able create a feasible, transparent decision model. This process straddles normative decision-making (how an individual *should* make a decision) and purely descriptive decision-making (how an individual *really* makes a decision). This prescriptive approach sacrifices external validity for conceptual accuracy. Indeed the context of the decision problem can result in changes to the decision structure [17], [18]. It is important to note that MAUT represents one of many different methodologies to analyse decision-making. While an in-depth discussion of the many decision-making methodologies would be inappropriate for this paper a list of important factors to my choice of MAUT is important to verify its applicability. Due to the uncertain nature of natural and man-made disaster it is important that the chosen methodology handle probabilistic factors and the quantitative manipulation of these elements. Non-linear preferences are also important to optimal decision-making and leads toward the use of MAUT. The use of discrete membership for both objective and probability functions is explicit in MAUT. Finally the axiomatic basis of MAUT verifies that recommendations do not violate logical, mathematical rules.

Green [19] provides a review of the use of operational research on emergency organizations. Of particular interest is the prominent use of multi-criteria decision analysis within fire services. Many operational research projects attempt to optimize resources and maximize the protection of the public through the correct placement of fire stations and related resources [20], [21].

Nuclear emergency management has also made extensive use of MAUT theory. The International Chernobyl Project which began in 1990 was commissioned through the European Communities to analyze and create decision-making models to inform DMs in cases of nuclear emergency [22], [23]. The Chernobyl Project conferences identified social, political and economic objectives that can be affected by the decisions made in the nuclear industry.

The Configurable Emergency Management and Planning System (CEMPS) is an example of a spatial decision support system to facilitate emergency evacuation. The primary goal of this system is to utilize traffic and road network to facilitate routing, queuing, and destination decisions by DMs [24], [25], [26]. The CEMPS system integrates a simulation model into a GIS framework to analyze policy actions that will affect roadway congestion during full-scale evacuation of the populace. Cova [27] takes a different approach to modelling evacuation through the creation of credible emergency planning zones (EPZs). Cova's population-based road networks create a map that predicts areas of high congestion during evacuation scenarios. Evacuation triggers are analyzed according to the modelling of wild fire spread. This model analyses the probable spread of fire gathered from remote sensing tools of fire-prone areas. This is then integrated into the population-based network map to predict fire spread and provide the basis for evacuation of at-risk neighbourhoods [28], [29].

A limited portion of the evacuation literature deals with the actual evacuation decision made by emergency officials. Regnier [30] discusses the use of meteorological forecasting to inform evacuation decisions for hurricane events in the United States. Regnier advocates simple decision tools that utilize forecasting probability models and geological information to identify accurate timeframes in which the evacuation decision should be made [31]. Regnier's conclusion was that evacuation decisions could be improved and false evacuations minimized by taking into account the variation in hurricane forecasting. The use of forecasting data as the probability model in a decision system is combined with a simple objective function. The objective function in this instance is an approximation of aggregate cost of evacuation for each mile of coastline compared to the cost of a failure to evacuate in case of catastrophic disaster [32].

The goal of the ERGO-based decision model for evacuation will be to develop a multi-objective utility function for emergency managers. This will add to existing literature in a number of ways: 1) provide explicit objective list of a wide range of stakeholders for evacuation planning, 2) develop an influence diagram that couples the multiple objectives with the hazard profile, 3) establish guidelines for risk thresholds; levels of risk at which evacuation actions should be taken.

3. Evacuation Objective Elicitation

Evacuation Responsiveness by Government Organizations (ERGO) has been tasked with an analysis of evacuation policies across the European Union and Japan. Participating EU countries include the United Kingdom, Germany, Spain, Belgium, Sweden, Denmark and Iceland. Japan was also included in the analysis as a non-EU benchmark for comparison purposes. Due to the catastrophic hazards that may occur prior to evacuation actions the importance of preparation is of high concern for emergency managers as well as other organizations tasked with public protection.

A list of ERGO participants and stakeholder organizations can be seen in Table 1.

Table 1. ERGO Participating Countries and Organizations

Participating countries	United Kingdom, Germany, Spain, Belgium, Sweden, Denmark, Iceland & Japan
Organizations included within each country	All levels of government, Police, Fire, Ambulance, Non-Governmental Organizations, Transportation Services, Private Consulting Firms, Foreign Ministries, Academic Researchers

The extensive interviews performed are necessary in creating as complete a list as possible of objectives for the evacuation decision. The qualitative elicitation of objectives has been outlined by many authors [33], [34]. Bond [35] found that it is difficult for individuals to effectively articulate all of the objectives that underlay the problems with which they are faced. In order to overcome the problem of an incomplete objective list the ERGO data-gathering interviews included qualitative aids to developing objectives [36] as well as the use of multiple objective elicitation that were then verified from a master list [37]. These measures help to insure that a complete list of evacuation relevant objectives have been elicited from the various stakeholders.

This preliminary objective list was then presented to an advisory board meeting of the ERGO Project. This group provides constant guidance and feedback on the development of ERGO models and also suggests areas of improvement and criticism. The preliminary objective list for evacuation decisions is presented in Table 2.

Table 2. Preliminary Objectives and Attributes for Evacuation Decisions

Objectives	Attribute
1. Minimize Health and Safety Threat	
Minimize loss of life to population	Number of casualties
Minimize injuries to population	Number of serious injuries
2. Minimize Indirect Economic Losses	
Minimize business disruption	Cost in pounds
Minimize personal disruption	Cost in pounds
3. Minimize Emergency Organizations Economic Losses	Cost in pounds
4. Minimize Panic and Disorder	Number of individuals who exhibit panicked behaviour
5. Minimize Public Disregard for Future Evacuation Orders	Number of individuals who fail to regard future evacuation orders
6. Maximize Public Confidence in Officials	Public approval of strategy

Possible attributes for each of the objectives are also shown in Table 2. These attributes provide the basis on which a multi-attribute utility function may be created to assess evacuation decisions.

4. Illustrative Decision Model Specification

An illustrative example of the decision model for evacuation will now be presented. This example utilizes a multi-attribute utility function that has been assessed through a limited number of utility and probability assessments from ERGO advisory board members. While it does not represent rigorous treatment of MAUT theory it will demonstrate the usefulness of the decision model in preparing for evacuation scenarios. The evacuation objective data that was gathered during the ERGO country visits will be applied to a hypothetical situation in order to identify risk thresholds. The probability distribution of the decision model also mirrors an actual risk profile of storm surge flooding that was identified during the data gathering. This model will then be used to answer the specific question of risk thresholds posed by emergency managers during the ERGO project.

The consequence of any given decision is determined not only by the objective function but also by a probability function of exogenous factors. This basic relationship is illustrated in Equation 1 [38].

$$a * \theta \rightarrow c \qquad (1)$$

This relationship indicates that the final consequence of any decision is dependent on the action of the DM as well as the state of nature (which is uncertain). A way to structure the relationship between decisions, objectives, and uncertainty is with the use of an influence diagram. An influence diagram provides simple graphical representations of the relationship between these different parts of the decision model through arcs and nodes. In this case the evacuation decision is the primary action and desirability of that action can be quantified through the multi-attribute utility function. The utility of each action, however, is also conditional on the state of nature related to the objective function. In this case it is the hazard profile (or probability structure) of an event that may call for evacuation action. A more complete treatment of influence diagrams can be found in Howard and Matheson [39] and Bodily [40].

A second source of uncertainty surrounding the evacuation decision besides the hazard profile is the inclusion of human behaviour within the model. While specific evacuation orders may be given by emergency officials the success of the action also depends on the reaction of the public to the evacuation order. Preliminary probability assessments must be made by emergency officials in order to account for these uncertain outcomes. The important relationship between evacuation orders and public response became apparent following Hurricane Katrina. The catastrophe that occurred in New Orleans is in many ways illustrates how the success of an evacuation is dependent on public response to official evacuation orders. Burnside [41] analysed public evacuation response in the greater New Orleans area following Hurricane Katrina. It was found that public evacuation decisions are related to information provided by authorities and personal acquaintances. Visual imagery provided by media sources as well as observable conditions all affected the evacuation decision. Additional factors that may influence the public response to an evacuation order may include return delays [42] and confidence in public officials [43].

Finally casualty rates for both evacuees and non-evacuees are necessary to calculate life costs within the objective function. Both evacuee and non-evacuee casualty rates are expressed within the influence diagram and can have major implications on the decisions made by emergency managers.

The evacuation actions that are available to emergency DMs are incorporated in the decision node of the influence diagram. In this example, decision-makers have four different strategies available to them. These strategies include: 1) no action, 2) hazard advisory, 3) mild evacuation order and 4) urgent evacuation order. These strategies will affect the economic and organizational costs identified in the objective function. It will also affect the number of individuals that heed the evacuation order as stated earlier. These strategies reflect evacuation decisions that can be taken by emergency mangers when faced with a storm surge hazard.

The illustrative decision model of evacuation decisions will incorporate the objective function that was collected during the ERGO site visits with the hazard (probability distribution) profile of a storm surge event, public response to evacuation orders and corresponding casualty rates. The relationship between these uncertain states of nature and the decision based on the objectives is shown in Figure 1.

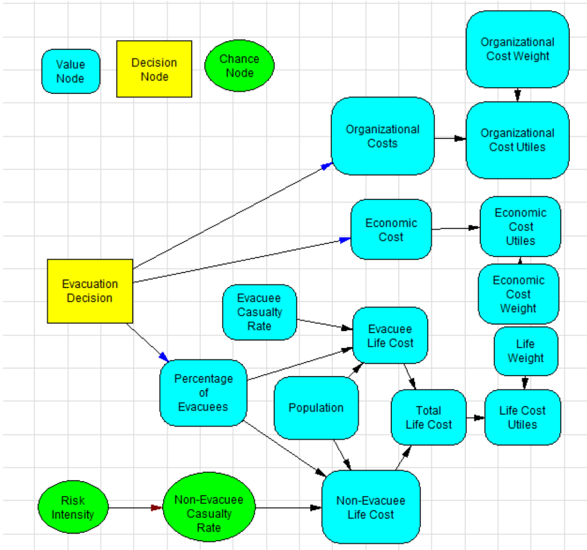

Figure 1. Influence diagram of illustrative decision model

The arcs in the influence diagrams represent the relationship between the model uncertainties (chance nodes), decision, and objective function (value nodes). Arcs establish how parent factors (i.e. decision node) affect value nodes. It also establishes joint, conditional and independent relationships between the value and chance nodes. Additional value nodes were included in the diagram in order to perform a sensitivity analysis on the decision model. The weight value nodes represent relative importance of the objectives between one another and will be discussed along with the utility elicitation of the objective function. The illustrative example utilizes only three of the identified objectives listed in Table 2. This was done for two primary reasons. First, the incomplete objective function was used in order to simplify the model during the utility elicitation process. Second, when presented to the ERGO advisory board these objectives (economic cost, organizational cost, and life cost) were identified as of primary concern to them as emergency decision-makers. The model itself utilizing this incomplete objective list was also deemed acceptable for preliminary purposes by the advisory board. Once again continual interaction between researchers and emergency officials will result in an evolving influence diagram for evacuation decisions. This preliminary model will be further developed to include all identified objectives as well as additional uncertainty concerning the public response to evacuation orders. Both conditional probabilities and utility functions must be quantified in order to complete the model. These initial assessments were performed through individual interviews with a limited number of emergency experts in the UK.

4.1. Multi-Attribute Objective Function Specification

In order to create a multi-attribute utility function, single utility functions must be assessed for every identified objective. In the illustrative case this would indicate the need for three separate utility assessments. The incomplete objective list utilized for this preliminary analysis is shown in Table 3.

Table 3. Example Objectives

Minimize loss of life (*x1*)
Minimize economic disruption (*x2*)
Minimize organizational costs (*x3*)

The functional form of the multi-attribute utility function is dependent on a number of axioms for normative decision-making. During the utility elicitation period axioms of preferential, utility, and additive independence were verified. Due to the verification of these axioms the additive multi-attribute utility function will be appropriate for the decision model (Equation 2).

$$u(x_1, x_2, x_3) = \sum_{i=1}^{3} k_i u_i(x_i) \qquad (2)$$

The combined utility of the multiple objectives is the sum of the single utility functions multiplied by a scaling constant that reflects the importance of each objective within the decision context. The scaling constants (k) are included as value nodes within the influence diagram. The scaling constant and utility functions are somewhat subjective as they represent a single DMs perception of the importance of any given objective. While this may be appropriate for any individual decision problem the subjective nature of the utility assessment must be acknowledged as it affects the external validity of any given decision model when applied to different situations.

A certainty equivalent (CE) utility assessment method was utilized to assess the single objective utility functions. The choice of CE as the utility assessment method may result in a bias toward risk aversion [44]. This may be problematic as the nature of the objectives as costs would lead to the assessed utility functions being risk *seeking*. At this stage in the analysis CE assessments methods will be utilized and the potential for bias explicitly stated to DMs when the results are analysed. Similarly, sensitivity analyses of the risk tolerance level will reveal if the bias introduced has a significant impact on the model. All objectives represent costs and qualitative assessments prior to the certainty equivalent method indicate that the general form of the utility function should be exponential functions of the form stated in Equation 3, where k is a constant and R is the risk tolerance of the DM.

$$u(x_i) = k_i - e^{-x_i/R} \qquad (3)$$

These results are unsurprising as the qualitative assessment done prior to the utility quantification indicated the general form of the single objective utility functions.

The final step in the creation of the objective function is the assessment of k values to indicate the relative importance of each objective. Lottery weights will be utilized to assess the relative importance of each objective. The assessed weights indicate that life costs are of the greatest importance to emergency managers. Both economic costs and organizations costs are of negligible importance in the evacuation decision. While this may seem to simplify the problem, the probability assessment of uncertainty within the decision model will show how the trade-offs between the identified objectives can lead to very difficult evacuation decisions.

4.2. Probability Specification

A clear understanding of the hazard threatening an area is vital to understanding any mitigating action taken during an emergency. The illustrative case will utilize a storm surge risk profile as taken from participating ERGO countries. The storm surge hazard can threaten an area if rising water breaches built or natural flood defences. The duration of the threat is relatively short and therefore short term evacuations are a viable strategy to limit the loss of human life and injury. Information concerning the risk is received by emergency authorities from measurement stations and can predict the level of rising water up to 12 hours in advance. These probability distributions were gathered from historic tide level data gathered from local environment agencies. The forecasts that are received indicate the predicted level of water 12 hours in advance with a standard error of 50 centimetres ($x_{12} \sim N(x, 50)$). Forecasts nine hours in advance of have an improved standard error of 30 centimetres ($x_9 \sim N(x, 30)$).

The primary flood defense is the use of dykes surrounding populated regions. Emergency managers must decide upon evacuation strategies if there is a credible chance of water levels rising above flood defense levels. Given this information it is possible to create a hazard profile that will allow us to understand how different forecasts of the storm surge affect the objective function. Discrete probability distributions can be created using the forecasts that correspond to different risk forecasts. Given the height of dykes within the area it is then possible to find the probability of the defenses being overtopped. For example, given dyke heights of 8 meters and a forecast at 12 hours of $x_{12} \sim N(800, 50)$ there is a fifty percent chance of the defenses being breached, a twenty-one percent chance of the defenses being breach by 50 centimeters and a five percent chance of the defenses being breached by more than 100 centimeters. The intensity of the hazard in this example will affect the non-evacuee casualty rate in the influence diagram. By varying the hazard profile and the affect that it has on the objective function the optimal evacuation decision can be determined. Conditional probability distributions were gathered from expert practitioners.

5. Results and Sensitivity Analysis

The primary goal of this illustrative model is to identify at which levels of risk emergency managers should take evacuation procedures to mitigate the effects of storm surge. Table 4 & Table 5 show the utility of each evacuation strategy for both twelve and nine hour forecasts respectively. The evacuation strategies represent actions that can be taken by emergency managers during an uncertain flood event. The increasing order of strategies lead to increasing costs to emergency organizations and economic disruption balanced with larger numbers of the public evacuating prior to an event.

Specific assumptions for the completion of this analysis are that: 1) evacuation decisions are taken in time to allow for complete evacuations, 2) similar functional form of single attribute utility functions, 3) damage caused by breach of flood defences is static.

Table 4. Expected Utility Table (12 hour forecast)

		Evacuation Strategy			
		No Action	Advisory	Mild Evacuation Order	Urgent Evacuation Order
Surge Forecast	Breach %				
800	50.00	0.510	0.690	0.888	0.909
790	42.00	0.609	0.751	0.907	0.917
780	34.00	0.694	0.803	0.924	0.923
770	27.00	0.788	0.860	0.941	0.930
760	21.00	0.833	0.890	0.951	0.935
750	16.00	0.888	0.924	0.962	0.939
740	12.00	0.923	0.946	0.969	0.942
730	8.00	0.945	0.961	0.975	0.944
720	9.50	0.967	0.975	0.979	0.946
710	6.70	0.975	0.980	0.981	0.947
700	2.00	0.987	0.988	0.984	0.948
690	1.31	0.991	0.991	0.985	0.949

Table 5. Expected Utility Table(9 hour forecast)

		Evacuation Strategy			
		No Action	Advisory	Mild Evacuation Order	Urgent Evacuation Order
Surge Forecast	Breach %				
800	50.00	0.668	0.778	0.910	0.917
790	38.00	0.774	0.845	0.932	0.926
780	27.00	0.845	0.892	0.949	0.933
770	19.60	0.911	0.936	0.965	0.940
760	10.00	0.945	0.959	0.973	0.944
750	5.00	0.973	0.978	0.980	0.947
740	2.00	0.989	0.989	0.984	0.949

According to the objective function, the optimal evacuation decision for the various hazard profiles is the strategy with the highest utility score. The risk threshold or the point at which evacuation actions should be taken can also be seen from Table 4 & Table 5. Utilizing 12 hour forecasts an urgent evacuation order should be called if a forecast of 790 centimetres or greater is received. Mild evacuation orders should be taken between 710 and 780 centimetre forecasts. The more precise measurements that arrive at nine hours results in a much more compact expected utility table. The range for which evacuation procedures should begin at twelve hours ($x_{12} > 710$) is greater than the range at nine hours ($x_9 > 750$).

The use of sensitivity analysis will help the analyst to understand how changing the parameters of the model will affect the decision outcome. The sensitivity analysis was a systematic process of creating ranges at $\pm 50\%$ of the corresponding value and chance node in the influence diagram. The decision model is then rerun holding all other nodes constant. The same type of analysis was done to the risk tolerance (R) values for the single utility functions.

The sensitivity test was run on the unconditional predecessor value nodes in the influence diagram. The tornado diagram for these results indicates that "life weight" is the most sensitive to change. All other unconditional predecessor value nodes in the influence diagram were robust to variation. This result indicates that the weighting assessment during the elicitation of the multi-attribute utility function is vital to the decision model. A sensitivity analysis of the remaining chance nodes (risk intensity & non-evacuee life cost) were then performed. "Non-evacuee life cost" is sensitive to changes of the parameters; however, the "risk intensity" has the greatest effect on the optimal evacuation decision.

Managers can also utilize this information to know when actions must be taken to mobilize resources or notify the public of incoming hazardous events. The improvement in precision of the forecasting between 12 hours and 9 hours can result in a significant reduction in false evacuations as the DMs need prepare for an actual evacuation when the probability of the hazard is much greater. The sensitivity analysis also provides insight into the parameters that have the greatest effect on the decision. These results will lead the analyst to critically assess these parameters during future elicitation and data-gathering activities. While a majority of the parameters in this example are taken from preliminary ERGO results many of the uncertainties within the model were elicited from a limited number of actual interviews with emergency managers. Continued communication with ERGO participants will help to gather additional information concerning human behavior during evacuation actions, objective importance and non-evacuee casualty rates.

6. Additional Decision Model Uses

While the focus of this analysis has been on the creation of risk thresholds to aid emergency managers' evacuation decisions, the MAUT process can be used for many different purposes regarding evacuation planning and mitigation. Indeed the varied uses of decision modelling should also be acknowledged as beneficial for the participating emergency service organizations. Additional benefits of the MAUT process can include: 1) an explicit list of objectives that DMs must consider in making their decision and the associated value trade-offs, 2) evacuation mitigation policy appraisal and 3) scenario building for training.

The qualitative process of creating an objective list for the evacuation decision was of vital importance to the MAUT process. The wide range of stakeholders that were consulted during the initial data-gathering visits and the creation of a master objective list during the ERGO advisory board meeting have two primary purposes. First, the identification of all important objectives is vital in making the best possible decision. Second the breadth of stakeholders increases confidence in the resultant model. This will increase the likelihood that this evacuation decision model and the results from it are acceptable and utilized by emergency officials within the ERGO countries. The quantification of the objective list which leads to the creation of a multi-attribute utility function can provide insight into the trade-offs between these conflicting values. When interviewed, many of the emergency managers felt uncomfortable directly assessing their own trade-offs. In particular they had difficulty in accepting explicit currency values for the loss of life. The quantification process of objectives can identify the value trade-offs that are implicitly gathered from the DM. These results must then be verified by the individual DM in order to assure that they adhere to the expectations of the emergency manager.

A clear understanding of values and uncertainties surrounding the evacuation decision can also be used to evaluate policies to improve evacuations. An example of this would be if DMs are faced with two possible actions to facilitate evacuations. One option is to improve the precision of forecasting technology. A second option is a policy to improve structures that will result in a reduction of non-evacuee casualties due to the hazard. Once the cost for each intervention has been assessed the changes that they would propose in the decision model can be evaluated to find which will have the greater impact on the decision itself. This can help DMs choose the best evacuation-related mitigation policy that fits their identified values.

Training exercises can be of immense benefit to emergency managers in preparation for actions such as evacuation. Through the decision model, scenarios can be created by varying the ranges of the chance nodes in the influence diagram. Also by relaxing the ranges of objectives new situations can be created that stretch the limits of an emergency managers' perception. An example of this would be a sharp increase in the number of residents in an at-risk area. The strain of this increase in the population parameter can then be modeled in the respective nodes within the influence diagram. The decision analysis can then be rerun to find how this new scenario changes the optimal decisions. This process of scenario building can lead to an increase in emergency preparedness as well as a better understanding of how identified parameters can influence the evacuation decision.

7. Conclusion & Scope for Improvement

The ERGO project represents one of the most inclusive international evaluations of emergency management. Multi-attribute utility theory can aid emergency managers understand the conflicting values that must be weighed in preparation of the evacuation process. An evaluation of the objectives of various stakeholders across eight different countries resulted in a preliminary list of objectives that emergency managers must evaluate during the evacuation decision.

An illustrative example of the decision model was created utilizing a limited number of utility and probability assessments to complete the decision model. The purpose of the example was to identify levels of risk at which evacuation actions must be taken. The hazard profile that was utilized in this example is taken from an ERGO participating country and models the likelihood of storm surge threatening the area. The results illustrate the creation of risk thresholds as well as the difference in optimal decisions given varying levels of precision within the forecasts. This will lead future data gathering to critically assess ways in which emergency managers measure casualty rates and the objective function weight elicitation.

Future data gathering will also attempt to include the possibility of biases that occur due to cognitive decision heuristics as well as the exact methods utilized in the quantification of the utility and probability functions. One aspect of this problem was briefly explained during the discussion of the utility elicitation. A variety of utility elicitation methods may be performed to limit this problem. A second possible problem may come from difficulty that DMs have in assessing their preference due to anchoring, framing and other decision heuristics. An example of this problem is in the utility assessment of life costs in the evacuation decision. The framing of the life cost as either a loss of life or saving life can result in very different results in risk tolerances. The use of prescriptive decision analysis will allow for a pragmatic approach where a method can be found that best fits the decision process of the interviewed emergency managers [45].

It is vital for emergency managers to consistently account for the various conflicting values that are inherent in the evacuation decision. Multi-attribute utility theory (MAUT) has been used to identify these values and an illustrative decision model has been created to identify risk thresholds for a storm surge scenario. Further data must be elicited from ERGO participants in order to further populate the probability and utility functions within the decision model. This will allow for more robust results as well as additional uses for the decision model including evacuation policy analysis and creation of training scenarios.

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