Multilevel Fuzzy Approach to the Risk and Disaster Management

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Abstract: In this paper a short general review of the main characteristics of risk management applications is given, where a hierarchical, multilevel risk management method can be applied in a fuzzy decision making environment. The given case study is a travel risk-level calculation based on the presented model. In the last section an extended model and a preliminary mathematical description is presented, where the pairwise comparison matrix of the grouped risk factors expands the previous principles.

Keywords: risk management; fuzzy multilevel decision making; comparison matrix

1 Introduction

The economical crisis situations and the complex environmental and societal processes over the past years indicate the need for new mathematical model constructions to predict their effects. The health diagnostic as a multi-parameter and multi-criteria decision making system is, as well, one of the models where, as in the previous examples, a risk model should be managed.

Haimes in [1] gives an extensive overview of risk modeling, assessment, and management. The presented quantitative methods for risk analysis in [2] are based on well-known mathematical models of expert systems, quantitative optimum calculation models, statistical hypothesis and possibility theory. The case studies present applications in the fields of economics and environmental protection. It is observable that the statistical-based numerical reasoning methods need long-term experiments and that they are time- and computationally demanding. The complexity of the systems increases the runtime factor, and the system parameter representation is usually not user-friend. The numerical methods and operation research models are ready to give acceptable results for some finite dimensional problems, but without management of the uncertainties. The complexity and uncertainties in those systems raise the necessity of soft computing based models.

Nowadays the expert engineer's experiences are suited for modeling operational risks, not only in the engineering sciences, but also for a broad range of applications [13]. Wang introduces the term of risk engineering related to the risk of costs and schedules on a project in which there is the potential for doing better as well as worse than expected [3]. The presented case studies in his book are particularly based on long-term engineering experiences, for example on fuzzy applications, which offer the promised alternative measuring of operational risks and risk management globally.

The use of fuzzy sets to describe the risk factors and fuzzy-based decision techniques to help incorporate inherent imprecision, uncertainties and subjectivity of available data, as well as to propagate these attributes throughout the model, yield more realistic results. Fuzzy logic modeling techniques can also be used in risk management systems to assess risk levels in cases where the experts do not have enough reliable data to apply statistical approaches.

There are even more applications to deal with risk management and based on fuzzy environments. Fuzzy-based techniques seem to be particularly suited to modeling data which are scarce and where the cause-effect knowledge is imprecise and observations and criteria can be expressed in linguistic terms. [4]

The structural modeling of risk and disaster management is case-specific, but the hierarchical model is widely applied. The system characteristics are as follows: it is a multi-parametrical, multi-criteria decision process, where the input parameters are the measured risk factors, and the multi-criteria rules of the system behaviors are included in the decision process. The Analytical Hierarchy Process (AHP) expands this complex system with the pairwise comparison of the factors' importance and interaction [5].

In this paper, after a short general review of the main characteristics of risk management applications, a hierarchical, multilevel risk management method will be presented in a fuzzy environment. The given case study is a travel risk-level calculation based on the presented model. In the last section a preliminary mathematical description is presented based on a pairwise comparison matrix and AHP expanded principles.

2 Risk Management

Risk management is the identification, assessment, and prioritization of risks, defined as the effects of uncertainty of objectives, whether positive or negative, followed by the coordinated and economical application of resources to minimize, monitor, and control the probability and/or impact of unfortunate events [6].

The techniques used in risk management have been taken from other areas of system management. Information technology, the availability of resources, and other facts have helped to develop the new risk management with the methods to identify, measure and manage the risks, thereby reducing the potential for unexpected loss or harm [7]. Generally, a risk management process involves the following main stages.

The first step is the identification of risks and potential risks to the system operation at all levels. Evaluation, the measure and structural systematization of the identified risks, is the next step. Measurement is defined by how serious the risks are in terms of consequences and the likelihood of occurrence. It can be a qualitative or quantitative description of their effects on the environment. Plan and control are the next stages to prepare the risk management system. This can include the development of response actions to these risks, and the applied decision or reasoning method. Monitoring and review, as the next stage, is important if we are to have a system with feedback, and the risk management system is open to improvement. This will ensure that the risk management process is dynamic and continuous, with correct verification and validity control. The review process includes the possibility of new additional risks and new forms of risk description. In the future the role of complex risk management will be to try to increase the damaging effects of risk factors.

2.1 Fuzzy Risk Management

Risk management is a complex, multi-criteria and multi-parametrical system full of uncertainties and vagueness. Generally the risk management system in its preliminary form contains the identification of the risk factors of the investigated process, the representation of the measured risks, and the decision model. The system can be enlarged by monitoring and review in order to improve the risk measure description and decision system. The models for solving are knowledge-based models, where linguistically communicated modeling is needed, and objective and subjective knowledge (definitional, causal, statistical, and heuristic knowledge) is included in the decision process. Considering all these conditions, fuzzy set theory helps manage complexity and uncertainties and gives a user-friendly visualization of the system construction and working model.

Fuzzy-based risk management models assume that the risk factors are fuzzified (because of their uncertainties or linguistic representation); furthermore the risk management and risk level calculation statements are represented in the form of *if premises then conclusion* rule forms, and the risk factor calculation or output decision (summarized output) is obtained using fuzzy approximate reasoning methods. Considering the fuzzy logic and fuzzy set theory results, there are further possibilities to extend fuzzy-based risk management models modeling risk factors with type-2 fuzzy sets, representing the level of the uncertainties of the membership values, or using special, problem-oriented types of operators in the fuzzy decision making process.

The hierarchical or multilevel construction of the decision process, the grouped structural systematization of the factors, with the possibility of gaining some subsystems, depending on their importance or other significant environment characteristics or on laying emphasis on risk management actors, is a possible way to manage the complexity of the system. Carr and Tah describe a common hierarchical-risk breakdown structure for developing knowledge-driven risk management, which is suitable for the fuzzy approach [8].

Starting with a simple definition of the risk as the adverse consequences of an event, such events and consequences are full of uncertainty, and inherent precautionary principles, such as sufficient certainty, prevention, and desired level of protection. All of these can be represented as fuzzy sets. The strategy of the risk management may be viewed as a simplified example of a precautionary decision process based on the principles of fuzzy logic decision making [9].

3 Grouped, Weighted Fuzzy Model

Based on the main ideas from [8] a risk management system can be built up as a hierarchical system of risk factors (inputs), risk management actions (decision making system) and direction or directions for the next level of risk situation solving algorithm. Actually, those directions are risk factors for the action on the next level of the risk management process. To sum this up: risk factors in a complex system are grouped to the risk event where they figure. The risk event determinates the necessary actions to calculate and/or increase the negative effects. Actions are described by ‘if … then’ type rules.

With the output those components frame one unit in the whole risk management system, where the items are attached on the principle of the time-scheduling, significance or other criteria (Fig. 1). Input Risk Factors (RF) grouped and assigned to the current action are described by the Fuzzy Risk Measure Sets (FRMS) such as ‘low’, ‘normal’, ‘high’, and so on. Some of the risk factor groups, risk factors or management actions have a different weighted role in the system operation. The system parameters are represented with fuzzy sets, and the grouped risk factors values give intermitted results [14]. Considering some system input parameters, which determine the risk factors’ role in the decision making system, intermitted results can be weighted and forwarded to the next level of the reasoning process.

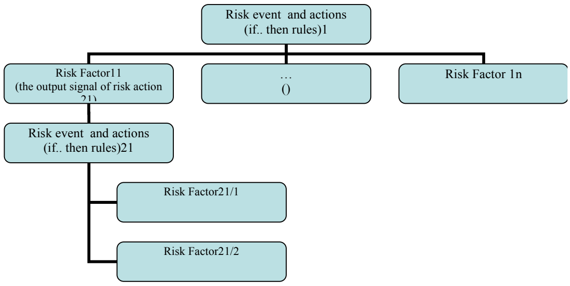

Figure 1
The hierarchical risk management construction

3.1 Disaster Management - Case Studies

Disaster event monitoring as one of the steps in risk and crisis management is a very complex system with uncertain input parameters. Fuzzified inputs, the fuzzy rule base, which is constructed using objective and subjective definitional, causal, statistical, and heuristic knowledge, is able to present the problem in a user-friendly form. The complexity of the system can be managed by the hierarchically-structured reasoning model, with a thematically-grouped, and if necessary, gained risk factor structure.

Crisis or disaster event monitoring provides basic information for many decisions in today's social life. The disaster recovery strategies of countries, the financial investments plans of investors, or the level of the tourism activities all depend on different groups of disaster or crisis factors. A disaster can be defined as an unforeseen event that causes great damage, destruction and human suffering, evolved from a natural or man-made event that negatively affects life, property, livelihood or industry. A disaster is the start of a crisis, and often results in permanent changes to human societies, ecosystems and the environment.

Based on the experts' observations [11], [12], the risk factors which prejudice disaster situation can be classified as follows:

- natural disasters;

- man-made disasters (unintended events or willful events).

Natural disasters arise without direct human involvement, but may often occur, because of human actions prior, during or after the disaster itself (for example, a hurricane may cause flooding by rain or by a storm surge).

The natural disasters can also be grouped primarily based on the root cause:

- hydro-meteorological disasters: floods, storms, and droughts;

- geophysical disasters: earthquakes, tsunamis and volcanic eruptions;

- biological disasters: epidemics and insect infestations;

or they can be structured hierarchically, based on sequential supervention.

The example, presented in this paper, is constructed based on the first principle, with fuzzified inputs and a hierarchically-constructed rule base system (Figure 2). The risk or disaster factors, as the inputs of one subsystem of the global fuzzy decision making system, give outputs for the next level of decision, where the main natural disaster classes result is the total impact of this risk category.

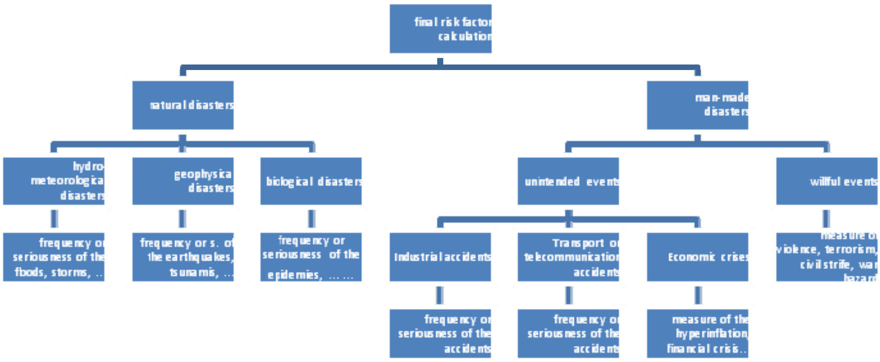

Figure 2
Hierarchically constructed rule base system

This approach allows additional possibilities to handle the set of risk factors.

It is easy to add one factor to a factors-subset; the complexity of the rule base system is changed only in the affected subsystem.

In different seasons, environmental situations etc., some of the risk groups are more important for the global conclusion than others, and this can be achieved with an importance factor (number from the [0,1]).

Man-made disasters have an element of human intent or negligence. However, some of those events can also occur as the result of a natural disaster. Man-made factors and disasters can be structured in a manner similar to the natural risks and events. One of the possible classifications of the basic man-made risk factors or disaster events (applied in our example) is as follows:

1. unintended events:

   - Industrial accidents (chemical spills, collapses of industrial infrastructures);

   - Transport or telecommunication accidents (by air, rail, road or water means of transport);

- Economic crises (growth collapse, hyperinflation, and financial crisis);

2. willful events (violence, terrorism, civil strife, riots, and war).

In the investigated example, the effects of man-made disasters as inputs in the decision making process are represented with their relative frequency, and the premises of the related fuzzy rules are very often represented with the membership functions: never, rarely, frequently, etc.[1]

The input parameters are represented on the unit universe [0,1] with triangular or trapezoidal membership functions describing the linguistic variables such as the frequency of the floods, for example: "low", "medium" or "high" (Fig. 3). The system was built in the Matlab Fuzzy Toolbox and Simulink environment.

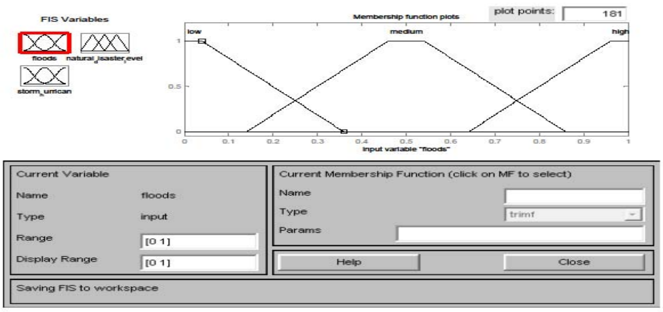

Figure 3

Membership functions of the flood frequencies

The risk and disaster factors are grouped in two main groups: human- and nature-based group. The inputs are crisp, but the rule base system is hierarchically constructed (Fig. 4), and the decision making is Mamdani type approximate reasoning with basic *min* and *max* operators.

1 The Matlab Fuzzy Toolbox and Simulink elements were in the preliminary, partial form constructed by Attila Karnis, student of the Óbuda University as the project on the course "Fuzzy systems for engineers".

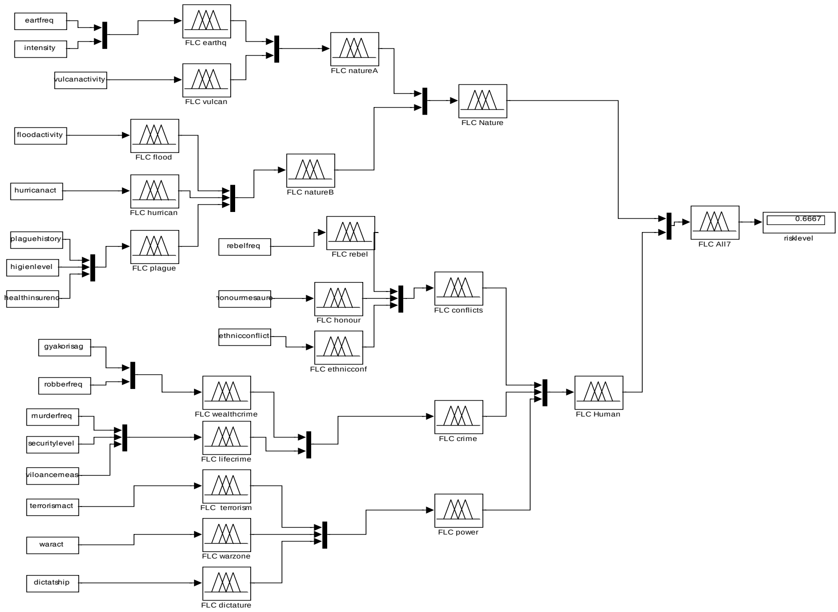

Figure 4

The system construction for the effects of disasters to calculate the travel risk level in a country

The final conclusion based on both disasters' as risk factors' groups is shown in Figure 5.

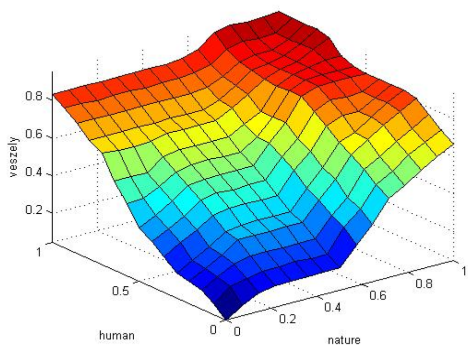

Figure 5

The final conclusion based on both disasters' as risk factors' groups

4 First Step to the Fuzzy AHP Model for Group-based Risk Management Model

Let $X_1, X_2, ..., X_n$ be the set of elements in a decision making system. It is a natural way to use the framework of a $A_{n\times n}$ square matrix to represent the pairwise comparisons of the dominance and interaction of those elements. Analytical Hierarchy Process (AHP) is a method for estimating the preference values from the pairwise comparison matrix. APH allows for the consideration of both qualitative and quantitative aspects of the decision, expanding the decision with the one-to-one comparison of the objectives, criteria, constraints or alternatives in the system model. The pairwise comparison in the AHP assume that the decision-maker can compare any two elements, for example X_i and X_j at the same level of the hierarchy in the system and provide a numerical value a_{ij} for the ratio of their importance. Saaty suggests using scale 1 to 9 to describe the preference measures [5], but in different applications there are presented other possible scales too [10].

Let $a_{ij} > 1$ if the element X_i is preferred to X_j, correspondingly, the reciprocal property $a_{ji} = 1/a_{ij}$ for i=1,2,...n, j=1,2,...n.

Each set of comparisons for a level with n elements requires $\frac{n\cdot(n-1)}{2}$ judgments, which are further used to construct a positive reciprocal matrix $A_{n\times n}$ of pairwise comparisons [10].

Let us interpret the comparison matrix $A_{n\times n}$ as the matrix of the dominance measures regarding the set of risk factors in a risk management system.

If the factors are grouped, and the groups are more or less independent, the comparison matrix has the block diagonal matrix form, and this allows us to pare down the computation complexity.

Example. Let $X_1, X_2, ..., X_n$ be the set of risk factors grouped in p groups, and let it contain the first factors group the factors X_1, X_2, X_3. The pairwise comparison of them is represented with the 3×3 dimensional sub-matrix A_{11}. The further representations are similar to this, so the next to last group contains two factors: X_{n-2}, X_{n-1}, with the 2×2 dimensional sub-matrix $A_{p-1,p-1}$, the last group holds only one factor.

$$A=\begin{bmatrix} a_{11} & a_{12} & a_{13} & & & \\ a_{21} & a_{22} & a_{23} & 0 & 0 & 0 \\ a_{31} & a_{32} & a_{33} & & & \\ & 0 & \ddots & 0 & & 0 \\ & 0 & 0 & a_{n-2,n-2} & a_{n-2,n-1} & 0 \\ & & & a_{n-1,n-2} & a_{n-1,n-1} & \\ & 0 & 0 & 0 & & a_{nn} \end{bmatrix}=\begin{bmatrix} A_{11} & 0 & 0 & 0 \\ 0 & \ddots & 0 & 0 \\ 0 & 0 & A_{p-1,p-1} & 0 \\ 0 & 0 & 0 & A_{p,p} \end{bmatrix}$$

It is natural that the comparison values a_{ii} are units, $a_{ii}=1$ for all i=1,2,...n.

Let $x=(x_1,x_2,...,x_n)$ be the actual input vector of the risk factors' vector $X=(X_1,X_2,...,X_n)$. The influence of the pairwise dominance comparison of the factors on the actual input vector can be represented as a transformation described with the matrix operation $A\cdot x^T$. The goal is to forward a weighted input vector to the system, where the weight-multiplier λ holds up the information about the pairwise dominance comparison of the input factors:

$A\cdot x^T=\lambda\cdot x^T$.

The method for computing the λ multiplier can be the eigenvalue method. On a practical score only real eigenvalues can be accepted. If there are not real eigenvalues in the set of solutions, the multiplier λ is a unit one, $\lambda=1$.

If there exists more than one solution with the proposed conditions, the chosen one should be the eigenvalue which keep the input vectors in their universe, but permits the highest efficiency of the decision. The AHP should be applied before the risk level calculation or decision making process.

The open problems are:

- to find the best way to create pairwise comparison of the factors, because the values are the judgments obtained from an appropriate semantic scale. In practice the decision-makers usually give some or all pair-to-pair comparison values with an uncertainty degree rather than precise ratings;
- to adjust the scale of the comparison values to keep the weighted input vector in their universe, but permitting the highest efficiency of the decision;
- to build up a fuzzy AHP model for the preliminary comparison of the risk factors in the risk management system.

Conclusions

Risk management applications are complex, multi-criteria and usually multilevel decision systems, required to manage uncertainties. The fuzzy environment is able to represent the ambiguous risk factors and rules in an acceptable form, where the risk factors are grouped based on their roles in the decision-making system. The given case study is a travel risk-level calculation based on the presented model.

The pairwise comparison matrix is the first step in introducing the fuzzy AHP model for the multilevel, hierarchically-structured risk management system, with further open problems and the possibility for fine tuning in the reasoning process.

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References

[1] Haimes, Y. Y., *Risk Modeling, Assessment, and Management*. 3rd Edition. John Wiley & Sons (2009)

[2] Vose, D., Risk Analysis: a Quantitative Guide, 3rd Edition. John Wiley & Sons (2009)

[3] Wang, J. X., Roush, M. L., http://www.amazon.com/gp/product/0824793013/ref=pd_lpo_k2_dp_sr_2?pf_rd_p=1278548962&pf_rd_s=lpo-top-stripe-1&pf_rd_t=201&pf_rd_i=047199765X&pf_rd_m=ATVPDKIKX0DER&pf_rd_r=1NEWTG6PBE2QGGHKFGTY *What Every Engineer Should Know About Risk Engineering and Management*, Marcel Dekker Inc, (2000)[4] Kleiner, Y., Rajani, B., Sadiq, R., *Failure Risk Management of Buried Infrastructure Using Fuzzy-based Techniques*, Journal of Water Supply Research and Technology: Aqua, Vol. 55, No. 2, pp. 81-94, March (2006)

[5] Saaty, T. L., Vargas, L. G. *Models*, *Methods*, *Concepts and Applications of the Analytic Hierarchy Process*, Kluwer Academic press, (2001)

[6] Douglas, H. *The Failure of Risk Management: Why It's Broken and How to Fix It*. John Wiley & Sons. p. 46 (2009)

[7] http://www.scotland.gov.uk/Publications/2008/11/24160623/3

[8] Carr, J. H. M., Tah, V.: *A Fuzzy Approach to Construction Project Risk Assessment and Analysis: Construction Project Risk Management System,* Advances in Engineering Software, Volume 32, Number 10, pp. 847-857(11) October (2001)

[9] Cameron, E., Peloso, G. F. *Risk Management and the Precautionary Principle*: A Fuzzy Logic Model, Risk Analysis, Vol. 25, No. 4, pp. 901-911, August (2005)

[10] Mikhailov, L., *Deriving Priorities from Fuzzy Pairwise Comparison Judgements*, Fuzzy Sets and Systems Vol. 134, pp. 365-385, (2003)

[11] Yasuyuki Sawada, *The Imapct of Natural and Manmade Disasters on Household Welfare*, http://www.fasid.or.jp/kaisai/080515/sawada.pdf

[12] Didadster Definition, http://www.wordiq.com/definition/Disaster

[13] Németh-Erdődi, K., *Risk Management and Loss Optimiyation at Design Process of Products,* Acta Polytechnica Hungarica, Vol. 5, No. 3 (2008)

[14] Takács, M., *Structured Risk Management Model with Fuzzy Background*, Proc. of FSTA 2010, Tenth International Conference On Fuzzy Set Theory And Applications, Liptovský Ján, Slovak Republic, February (2010)