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Abstract

The intention of this document is to describe the role of decision support systems and decision support models in multi-risk assessment. We do not address the entire literature and all developments in this area, but focus on the way risk assessment is planned to be implemented in the European Union. Here we identify the needs for decision support models and suggest practical approaches that have the ability of being tested in one or several test areas of MATRIX and have potential use (to be explored in MATRIX WP8) for the European risk mapping process.

Keywords: decision support, multi hazard and risk, multi-risk assessment

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1 Introduction

We start with definitions for decision support systems (DSS) and decision models (DM) in chapter 2. Whereas DSS is specified as an information system for the support of decisions, DM is characterized as a methodology or system that allows for the selection of decisions, usually from a discrete set of alternatives. The purpose of risk assessment, as a result of risk mapping, is not to take decisions but rather to show and display the role of different risks with regards to their frequency and severity. However, there are decisions to be made in the risk assessment process when ranking different loss categories. Thus, risk assessment requires DSS and components of DM. DMs are even, more valuable in the risk management process, as they target decisions rather than assessment.

Chapter 3 refers to a selection of methods applied in the literature and in European projects. In chapter 4, the European risk assessment process is briefly described. Its methodological basis is described in the Commission Staff Working Paper “Risk Assessment and Mapping Guideline for Disaster Management” (Brussels, 21.12.2010, SEC (2010) 1626 Final). A possible methodology has been developed by the Federal Office of Civil Protection and Disaster Assistance (BBK, 2010) in Germany and is described in chapter 5. For any relevant risk, a set of scenarios should be designed. The frequency of the event and the severity of its impact will populate the risk matrix. The severity is expressed by an indicator variable that combines the severity of losses from five components: population, economy, ecology, infrastructure and intangible losses. As these losses can only be partially characterized in monetary terms, it is obvious that a methodology and scheme for ranking is essential. The development of this ranking scheme in a stakeholder process is the focus of the suggested decision support tool that we propose to develop and apply in the test cases.

Chapter 6 discusses some of the basic features of Multi-Attribute Value Theory (MAVT), which is essential to understanding chapter 7, which discusses the decision process and its underlying methodology for the ranking of losses in the risk assessment approach. Chapter 8 provides a summary of this study.

2 General aspects of DSS and DM

A decision support system (DSS) is a computer-based information system that supports organizational decision-making activities (Marakas 1999). It consists of at least three components: database, model(s) including user criteria, and a user interface. It helps to make informed (utilizing the database) and formal (utilizing the model) decisions.

A Decision Model (DM) represents the logic of a process models logic based on the inherent structure of that logic, eliminating style and other subjective preferences, ensuring a consistent and stable representation (von Halle & Goldberg 2009). DMs include a formulation stage, an evaluation stage and an appraisal stage. Whereas evaluation focuses on the algorithmic aspect of DM, the appraisal stage emphasizes the communication of DM by looking into the implications, possible alternatives, and sensitivities.

Decision models can be classified according to a number of criteria (Silver 1991; Sprague & Watson 1993):

A: The number of objectives
A1: Decision models with one objective
A2: Decision models with several (multi-) objectives

B: With regards to the level of information available to the decision maker, three categories can be distinguished:
B1: The environment within which the decision is to be taken is very well known so that a high level of knowledge and security in terms of the consequences dominates; deterministic models are appropriate.
B2: Situations that include risks and several possible outcomes and consequences of the decision are conceivable, outcomes depend on unforeseeable circumstances, but can be associated with probabilities so that probabilistic approaches are generally appropriate.
B3: High levels of uncertainty prevail; possible outcomes are not fully clear and cannot easily be associated with probabilities.

C: Temporal interdependencies of decisions may be distinguished by:
C1: static models
C2: dynamic models.

D: From the point of view of the decision maker, distinctions are usually drawn between individuals and institutions or groups.
D1: When the decision maker interacts with an individual, an understanding of the individual's perception of a certain environment, the possible decisions and their potential implications are of high relevance.
D2: When the decision maker interacts with a group or institution, group dynamic aspects and consensus seeking processes and methodologies become relevant.

With regard to the risk mapping process (further elaborated in chapters 4 and 5) which is based on scenarios associated with a frequency and a severity of loss (for population, economy, ecology, infrastructure, intangibles), the requirements include information systems, and thus a classical DSS, which may be specific to the hazard types and risks treated. The ranking of risks, based on the severity of losses in various sectors (population, economy, ecology, infrastructure, and intangible losses) requires a DM that allows stakeholders to develop this ranking in a rational and transparent way. As the risk mapping and assessment process deals primarily with the ranking of what risk and losses are of a higher or lower relevance, only a few of the listed criteria need to be considered. However, there is no DM required that selects the best alternative from a set of possibilities. Decisions have generally multiple objectives (A2). Very frequently, high levels of uncertainty prevail. Although dynamic risk models with temporal variations of vulnerability and exposure and/or temporal changes in the hazards – for instance, driven by climate change – are desirable, the current risk mapping scheme foreseen for Europe is rather static (C1). The national and/or regional scale of the assessment procedure also requires the involvement of many institutions (D2).

As multiple objectives and criteria are relevant in risk assessment, these aspects require specific consideration. Transparent and coherent support for the solution of complex decision situations, including facilitation and communication between involved stakeholders, is the target of Multi-Criteria Decision Analysis (MCDA). An alternative approach is known as Cost-Benefit Analysis (CBA), which is frequently used for the quantitative evaluation of decisions related to risk (French 1986, 1996, 2003). CBA requires the expression of all benefits and disadvantages of the decision process in monetary terms and the decision follows from a comparison of costs and benefits. Thus, CBA is only applicable if all relevant items can be expressed in monetary terms. However, risk assessment often involves non-monetary items. If assets such as the environment, security, cultural heritage and other intangibles, which cannot readily be expressed in monetary terms, are important, CBA is difficult if not impossible to apply and MCDA is the preferred approach. The developers of MCDA consider the fact that the subjectivity in decision making is explicitly and deliberately included, and provides a clear advantage as long as transparency and traceability of the analysis is guaranteed. In addition, by providing a sound framework for sensitivity analysis, MCDA offers valuable support for consensus finding within decision-making groups. These items will be further explored in chapter 6.

3 Some decision support models in current use

As the main purpose of this paper is the design of the methodology for developing a ranking scheme for the societal impact of a particular scenario, we do not attempt to provide a comprehensive overview on available decision support models.

A number of information systems have been developed for specific types of disasters. HAZUS (Hazard US)[1] was designed to use state-of-the-art geographic information system software to map and display hazard data and the results of damage to building infrastructure and the associated economic loss estimates in the United States. It has been commissioned by the US Federal Emergency Management Agency (FEMA), which is part of the U.S. Department of Homeland Security (DHS). It allows users to estimate the impact of hurricanes, wind, floods and earthquakes on populations. It applies a standardized loss estimate in risk assessment methodology which is widely used in other countries, e.g. in Turkey and Taiwan.

ORTIS (Operational Risk Management Tool and Information System)[2] is a software tool specifically developed to support the risk management process on the scale of communities for Austria it refers to the risk matrix approach, where a large set of GIS-based maps and other information can be structured into ORTIS. It can also be used as a knowledge management database and finds wide applications in many communities in Austria. This is a commercial tool.

During the FP6 ARMONIA (applied multi-risk mapping of natural hazard for impact assessment) project, decision support software based on GIS data called Multi-Risk Land Use Management Support System (MURLMSS) was designed and developed. This decision support system is supposed to analyze multiple risk problems at local and regional scales. Its main objectives are:

- To provide a basis for planning in an area prone to multiple risks related to natural hazards.
- To include assessments of exposure and vulnerability.
- To support planners in understanding the implications of uncertainties and probabilities when making decisions concerning land use and for the location of strategic facilities.

The DSS developed during the ARMONIA project represents a qualitative approach using risk matrices to derive risk indicators which could be compared under different scenarios for a given hazard. Different scenarios for different hazard vulnerability mitigation measures can then be compared using a hazard category. The DSS includes the main stages of risk assessment:

- Context development
- Map and scenario selection
- Hazard analysis
- Exposed element analysis
- Vulnerability analysis
- Multiple criteria risk evaluation
- Risk assessment results (Output)
- Risk result comparisons among different scenarios

[1] www.fema.gov/plan/prevent/hazus/
[2] www.ortis-info.at/

Work package 5 of the ARMONIA project, (functional and technical architecture design of a decision support system for risk in form of special planning) contains a non-comprehensive list of other software-based DSS.

4 The (European) Risk Assessment Process

The current approach of the European Commission to Risk Assessment at the state level is documented in the "Commission Staff Working Paper. Risk Assessment and Mapping Guidelines for Disaster Management, Brussels, 21.12.2010, SEC (2010) 1626 final".

The following is summarized from this document.

Scope and Definitions:

National risk assessments include risks which are of sufficient severity to entail involvement by national governments in the response, in particular via civil protection services. Several countries have already produced national risk assessments or carried out substantive work in the area, in particular, UK, NL, DE, SE, FR, USA, Australia, Canada.

Previous Action includes:

- Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks, OJ L288, 6.11.2007, p.28.
- Council Directive 2008/114/EC on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection, OJ L345, 23.12.2008, p.75.
- Council Directive 96/82/EC on the control of major accident hazards involving dangerous substances, OJ L010, 14.01.1997, p. 13.

Role of Risk Assessment and Mapping within Disaster Risk Management:

Risk assessment and mapping are carried out within the broader context of disaster risk management. Risk assessment and mapping are the central components of a more general process which furthermore identifies the capacities and resources available to reduce the identified levels of risk, or the possible effects of a disaster (capacity analysis), and considers the planning of appropriate risk mitigation measures (capability planning), the monitoring and review of hazards, risks, and vulnerabilities, as well as the consultation and communication of findings and results.

Capacity analysis, capability planning, monitoring and review, consultation and communication of findings and results are not the subject of these guidelines. However, national risk assessments and mapping deliver the essential input for informed capacity building and the enhancement of both disaster prevention and preparedness activities.

Risk assessments and risk mapping contribute to ensuring that policy decisions are prioritised in ways to address the most severe risks with the most appropriate prevention and preparedness measures, and can in the process also become an instrument of solidarity.

Risk assessments deal with uncertainty and probabilities. These are the necessary subjects of a rational debate about the level of risk a Member State, or even the entire EU, may find acceptable when considering the costs of the associated prevention and mitigation measures.

Risk Matrix:

The risk management process has been standardised in the ISO 31000 standards, codified by the International Organization for Standardization (ISO)[3]. The purpose of ISO 31000 is to provide principles and generic guidelines on risk management which are universally recognized by practitioners, researchers, companies, etc. and that fit existing standards, methodologies and paradigms. ISO 31000 was published in November 2009. The standard does NOT aim at certification - as other ISO quality assurance guidelines do - but rather assuring the consideration of relevant aspects, the proper structure of an assessment process, and governance issues. The ISO standards are increasingly referenced in the corporate and public sector.

ISO 31000 contains the elements and interactions as identified in Fig. 1. The assessment of risk, which is the topic of MATRIX, includes, according to ISO 31000, three steps:

1. Risk identification.
2. Risk analysis.
3. Risk evaluation.

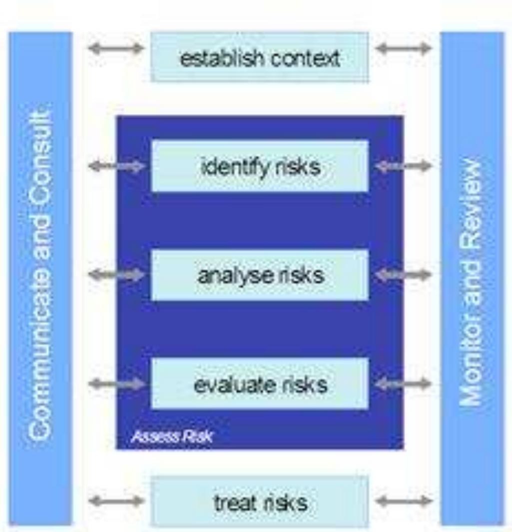

Fig. 1 Risk Management Process according to ISO 31000 (ISO 2009)

A risk matrix relating in two dimensions the likelihood and impact of a risk is a graphical representation of different risks in a comparative way (Fig. 2). The matrix is used as a visualisation tool when multiple risks have been identified to facilitate the comparison of different risks. The political/social impact can be measured using a qualitative scale comprising five classes, e.g., (1) limited/ insignificant, (2) minor/ substantial, (3) moderate/ serious, (4) significant/ very serious, (5) catastrophic/ disastrous.

[3] www.iso.ch

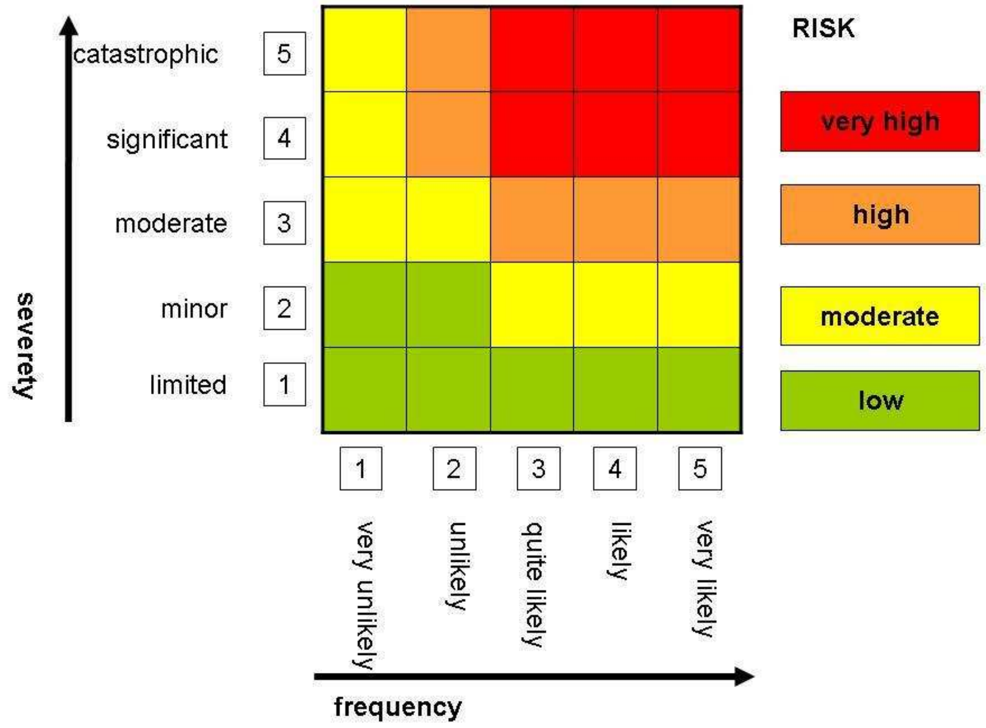

Fig. 2 Risk Matrix (based on BBK 2010)

The stages of risk assessment in the overall risk management process may be summarized as follows: At the beginning of the risk assessment process, there are three main preliminary steps to be made: 1) selecting the same target area (e.g., national); 2) selecting the same time window (e.g., short-term); 3) defining the same metric for the risk (e.g., impact measures). Once these steps have been made, we can start with the risk identification.

Scenarios:

ISO 31010 states that: "Many risk events may have a range of outcomes with different associated probability. Usually, minor problems are more common than catastrophes. There is therefore a choice as to whether to rank the most common outcome or the most serious or some other combination. In many cases, it is appropriate to focus on the most serious credible outcomes as these pose the largest threat and are often of most concern. In some cases, it may be appropriate to rank both common problems and unlikely catastrophes as separate risks. It is important that the probability relevant to the selected consequences is used and not the probability of the event as a whole" (ISO 2009a).

Generally, risk scenarios will be used both in the risk identification phase as well as at the risk analysis stage, with the latter aiming to establish quantitative estimates for impacts and probabilities. At the stage of risk identification, scenario building must be devised in the most inclusive way and may refer to rough estimates or qualitative analysis. At the stage of risk analysis, if possible, quantitative probabilities should be estimated for each scenario, e.g., using Bayesian methods, i.e., a statistical procedure which utilizes prior distribution data to assess the probability of a result.

As a matter of necessity, scenario building must be undertaken according to a minimum degree of common understanding among stakeholders. It will otherwise be impossible to compare the information presented by different Member States and may even lead to a distorted overall view. For this purpose, national risk identification would need to consider at least all significant hazards of an intensity that would on average occur once or more often in 100 years (i.e., all hazards with a annual probability of 1% or more) and for which the consequences represent significant potential impacts, i.e., the number of people affected being greater than 50, economic and environmental costs above € 100 million, and the political/social impact considered significant or very serious (level 4). Where the likely impacts exceed a threshold of 0.6 % of gross national income (GNI), less likely hazards or risk scenarios should also be considered (e.g., volcanic eruptions, tsunamis). Where the likelihood of a hazard leading to impacts exceeding the above thresholds is more than once in ten years, at least three scenarios with at least three different intensities should be included in the assessment. However, the number of necessary scenarios will depend on the size of the Member State, the number and extent of existing hazards and risks, and the level of advancement of the national risk assessment efforts. Experience from Member States indicates that between 50 to 100 scenarios may be necessary for a first risk identification exercise.

The "Commission Staff Working Paper" lists a number of EU initiatives with relevance to risk mapping, including EU legislation. They generally aim at the identification of areas of risk and the development of information for the public. These initiatives are:

- Floods
  The European Flood Directive requires Member States to identify areas of potential significant flood risk, based on a preliminary flood risk assessment which looks at, among other things, past floods, effectiveness of man-made flood defence infrastructure and long-term developments such as land use and climate change where relevant. For such areas, flood hazard and flood risk maps have to be prepared, identifying the potential adverse consequences to human health, economic activity, cultural heritage and the environment under a set of scenarios. The final step is to prepare flood risk management plans, which include flood risk management objectives, and the prioritising of measures for achieving these objectives.
- Droughts
  Droughts are natural disasters which can occur due to long absence of rainfall or due to heat waves. The Water Framework Directive deals with the management of scarce water resources and drought management, in particular with regards to the mitigation of the effects of floods. Member States authorities are required to monitor the quantitative status of groundwater and the quality and quantity of surface water (such as water flow levels).
- Industrial accidents
  The Seveso II Directive deals with the presence of dangerous substances in establishments. It covers industrial "activities" as well as the storage of dangerous chemicals. All operators of establishments coming under the scope of the directive need to send a notification to the competent authority and to establish a major accident prevention policy. In addition, operators of upper tier establishments need to establish a safety report, a safety management system and an emergency plan. Member States are obliged to pursue the aim of the directive through controls on the locations of new establishments, modifications to existing facilities and new developments such as transport links, locations frequented by the public and residential areas in the vicinity of existing establishments. In the long term, Land-use Planning Policies shall ensure that appropriate distances between hazardous

establishments and residential areas are maintained. Operators, as well as public authorities, have certain obligations to inform the public as to the nature of these establishments

- European Critical Infrastructures
  Directive 2008/114/EC on the identification and designation of European Critical Infrastructures (ECIs) and assessment of the need to improve their protection focuses in a first step on the energy sectors (electricity, oil, gas) and transport infrastructures. Each designated ECI shall have an Operator Security Plan (OSP) covering the identification of important assets, a risk analysis based on major threat scenarios, vulnerability of each asset, and the identification, selection and prioritisation of countermeasures and procedures.

We do not assess the role of decision making for these cases and topics.

The "Commission Staff Working Paper" addresses explicitly the way uncertainties should be addressed. As a new aspect for the risk reduction community, it incorporates the precautionary principle, which is commonly applied in the evaluation of industrial risks, but not systematically used in risk assessment. It can emerge as a supplementary approach to the standard probabilistic procedures used so far.

Risk analysis should take into account the uncertainties associated with the analysis of risks. Uncertainties need to be understood in order to communicate risk analysis results effectively. Uncertainty analysis involves the determination of the variation of imprecision in the results, resulting from the collective variation in the parameters and assumptions used to define the results. Sources of uncertainty should be identified where possible and should address both data and model uncertainties. Parameters to which the analysis is sensitive should be identified and stated.

Sensitivity analysis:
Sensitivity analysis involves the determination of the size and significance of the magnitude of risks to changes in individual input parameters. It can help determine whether the assumptions underlying a prediction are robust, or whether further information needs to be gathered.

The precautionary principle:
Where the scientific evidence is weak, the precautionary principle can justify the inclusion of relevant risks assessed on a qualitative basis, especially when risks to the environment, human, animal and plant health are involved and where the consequences are likely to be substantial and irreversible, and the likelihood of the occurrence of a negative consequence cannot be assessed. The precautionary principle may be applied as a first step towards risk management. Temporary decisions may need to be taken on the basis of the qualitative or inconclusive evidence. At the same time, any precautionary action must be based on objective assessments of the costs and benefits of action and requires transparency in decision making. Where the precautionary principle is applied, additional efforts should be made to improve the available evidence base.

The ambitious objectives of the European risk mapping process, as documented and discussed here, will arise from individual European states based on different timelines and with emphasis on different hazards. An overview of the status and progress is currently not available. The interaction of MATRIX (WP8 Dissemination) with Civil Protection Agencies and other stakeholders through the National Hyogo Framework of Action Platforms aims at a better understanding of the boundary conditions and expected progress. The methodology proposed later in this document will be communicated within this context and possibly demonstrated in one of the MATRIX case studies.

5 The BBK Risk Assessment Methodology

In the following, we briefly describe the methodology of comparative risk assessment, as suggested by the Federal Office of Civil Protection and Disaster Assistance (Bundesamt für Bevölkerungsschutz und Katastrophenhilfe – BBK)[4] in Germany, the office that is responsible for the design of these concepts and their promotion them nationally and internationally. BBK understands the procedure outlined in the following as one possible way of risk mapping on a national scale. It is important to note that the procedure does NOT include a methodology on how to develop scenarios and on how to evaluate the severity of losses and consequently how to rank them. We propose that it is at this point that decision making should enter the risk assessment process. In order to clarify this, the BBK procedure is presented in detail below.

The BBK procedure is called risk matrix analysis and it is consistent with the internationally agreed upon standards on risk management (ISO31000 and ISO 31010, 2009). Disasters are first identified according to their typology and then characterized with scenarios that should cover several return periods. The analysis of the scenarios results in a level of severity. The risk matrix is then populated with the set of (frequency, severity) values derived from the scenarios. The scales of the risk matrix are essentially logarithmic and range in terms of occurrence probability from

1 - very unlikely
2 - unlikely
3 - rare
4 - likely
5 - very likely.

The severity ranges from

1 - limited
2 - minor
3 - moderate
4 - significant
5 - catastrophic.

The colour code in Fig. 2 indicates the areas of the risk matrix and the classification of risks, ranging from low to medium to high and very high.

The analysis then proceeds in five steps:

Step 1 - Identification of the spatial area of interest.
Step 2 - Identify hazards to be included in the risk analysis and develop scenarios.
Step 3 - Determination of the occurrence probability of scenarios.
Step 4 - Loss Analysis,
- Loss parameters and categories.
- Measuring severity,

Step 5 - Risk Matrix Entry.

[4] www..bbk.bund.de/EN/Home

Step 1: Spatial Scale of Analysis

The first step of the risk analysis consists in the identification of the spatial area for which the analysis will be done. The area should be precisely described including:

- General geography of the area (e.g., climate, land use).
- Population (number of people living, population density).
- Environment (e.g. protected areas).
- Economy (e.g. economic parameters, level of unemployment, tax income, etc.).
- Infrastructure (main infrastructures specifically energy, transportation, water supply).,

Map information, including infrastructure information should be available in a format appropriate for a GIS.

Step 2: Selection of Hazards – Development of Scenarios

The second step in the risk analysis identifies which hazards are to be included in the risk analysis. Once a specific hazard is identified it is necessary to develop a scenario as a basis for the risk analysis. A scenario must describe and document the considered event in enough details in order to allow the determination of probabilities and severity of its impact. The following parameters for a scenario must be considered:

- Hazard: Which event is under consideration?
- Site of occurrence: Where is the event occurring?
- Spatial extent: What extent is affected by the event?
- Intensity: How strong is the event?
- Event time: When does the event happen (season, day of time, etc.)?
- Duration: What is the duration of the event and its direct implications?
- Cause of the event: What circumstances cause the event?
- Course of the event: What is the development of the event?
- Warning time: Was the event expected? Could the population be prepared for it? Could the institutions and other players of risk management be prepared?
- Who and what is affected: Who and what is directly or indirectly affected by the event (people, objects, environment, etc.)? Here, a list of items to be protected should be provided, rather than statements of potential loss and damage.
- Reference events: Are there comparable events documented in the area of analysis or comparable areas?
- Further information: What is the level of preparedness of the responsible authorities, emergency services, and the general population? Information is required on the vulnerability and preparedness of the affected people, environment, assets, etc.

BBK employs as examples for scenarios the following:

- A hundred-year flood as an event with a regular return period
- A thousand-year flood as an extremely rare event
- An earthquake with a given magnitude that refers to standard safety considerations (475 return period)
- The release of a certain amount of toxic material.

Step 3: Probabilities of occurrence

The third step in the risk analysis is the determination of the occurrence probability of the previously identified scenarios. For classification purposes, the occurrence probability is scaled into 5 categories, referring to the risk matrix classification. The following identifies the category of occurrence probability, its classification, its annual frequency and its return period.

1 - very unlikely (occurs once in 100.000 years, has an annual exceedance probability of 0,00001)
2 - unlikely (occurs once in 10.000 years, has an annual exceedance probability of 0,0001)
3 - rare (occurs once in 1.000 years, annual exceedance rate is 0,001)
4 - likely (occurs once in 100 years, annual exceedance probability is 0,01)
5 - very likely (occurs once in 10 years, annual exceedance probability is 0,1).

It is important to know that the return periods and exceedance probabilities per year are statistical values. The concept behind this is the availability of an extremely long time series of events (millions of years essentially), from which the average return period may be determined. The return period does not necessarily mean that this time passes between one event and the next of the same magnitude. It only says that two events, which are temporarily separated by considerably less or considerably more than the return period are unlikely.

For many hazards, these return periods are routinely determined by the standard assessment methods. For other hazards, one has to rely on expert opinion and/or observations in other areas, countries, etc.

Step 4: Loss Analysis

To specify loss parameters, one has to identify first the sectors that are relevant for the risk analysis. Implications for different sectors and objects to be protected need to be analysed. In order to determine the extent of damage, a suitable loss parameter has to be identified, as outlined in Table 1. It is assumed that all losses are positive in sign, which is always the case with direct losses, but could be different with indirect losses.

Table 1 Loss parameters and categories.

Category	Abbreviation (subcatagory)	Loss parameter	Description	Unit
People	P1	Fatalities	Persons that die in the scenario within the area of analysis	number
	P2	Casualties	Persons who are injured in the area of analysis by the event or as a consequence of the event, to the extent that they need medical treatment. Here also, long term effects on health should be considered, but specifically identified.	number
	P3	Persons who need assistance for more than 2 weeks	Persons who need e.g., shelter, psychological help, or other measures of support that need to be provided by public or other institutions for more than 2 weeks.	number

	P4	People who need assistance up to 2 weeks	Persons who need shelter, psychological care or other support measures for less than 2 weeks.	number
Environ-ment	E1	Damage to environmental protected areas	Identification of protected areas, reservations, parks, etc., affected by the event.	hectare
	E2	Damage to the fluvial environment	Documentation of damage to river systems, lakes or coastal environments.	kilometer or hectare
	E3	Damage to ground water	Contamination of ground water	hectare
	E4	Damage to agricultural areas	Which areas utilized for agricultural production are affected and suffer losses.	hectare
Economy	F1	Direct losses	The total value of direct loss measured in the amount of resources necessary for reconstruction and rehabilitation.	Euro
	F2	Indirect losses	Total amount of indirect losses such as interruption of supply chains, store of production because of this, unemployment, etc.	Euro
	F3	Loss of economic power	Long-term loss of economic production capacity as a consequence of the event.	Euro
	F4	Loss of commercial and industrial earning power	Loss of tax revenues as a consequence of the event.	Euro
Infra-structure	I1	Interruption of fresh water supply	Duration and spatial extent of the interruption, number of affected persons and households.	hours, area, number
	I2	Interruption of energy supply	Duration and spatial extent of the interruption, number of affected people and households.	hours, area, number
	I3	Interruption of gas supply	Duration and spatial extent of the interruption, number of affected people and households.	hours, area, number
	I4	Interruption of tele-communication	Duration and spatial extent of the interruption; number of affected people and households.	hours, area, number
Intan-gibles	J1	Implications for public security	Extent of the impact on public security (public protests, vandalism, violence).	extent
	J2	Political implications	Extent of implications in the political administrative sector (e.g., demands for public action, political changes).	extent
	J3	Psychological implications	Extent of loss of trust in public and other institutions, such as the government, public administration, etc.	extent
	J4	Loss to cultural values	Loss of and damage to cultural and religious buildings, sites, values.	number of items, degree of loss

Developing score values for parameters:

The parameters of loss are often not comparable, as they cannot be expressed in one unit, for instance a monetary value. Instead, one characterizes the different loss parameters in terms of 5 categories:

1 - Irrelevant
2 - Small
3 - Moderate
4 - Large
5 - Catastrophic

Doing this requires the mapping (or normalization) of individual descriptions of losses into the scores. This requires stakeholder input and systematic and transparent evaluation and documentation using a DM. As only partial regulations are available in most countries for the appropriate identification, it is therefore necessary to develop the classification using a stakeholder and consensus driven approach. For instance, with regards to the sector 'people', one has to determine what numbers of fatalities, casualties; people in need of support could be appropriately classified into the above categories.

Overall severity of scenario loss:

The combination of the individual loss categories results in the overall severity of this scenario event. The overall loss category can be determined by various procedures must be selected by the involved participants of the risk analysis. The simplest way is to add the individual loss values and divide them by the number of loss parameters. A more sophisticated approach is to include weights for particular parameters of higher relevance than others. Again, stakeholder input and a DM is required for this step.

Step 5: Determination and visualisation of risk

The final results for a particular scenario can be inserted into the risk matrix at the appropriate location, determined by the severity or loss and the occurrence probability.

This should be done for the entire list of hazards of interest. For a particular hazard type, one can choose several scenarios, ranging typically from the regulatory one (e.g., 100-year flood) to the extremely rare one (1000-year flood).

In this simple procedure, the uncertainties associated with the risk assessment are not considered, representing a serious limitation.

Implications for MATRIX

Obviously, the BBK methodology outlined above does not explicitly address the following highly relevant issues for the design of risk matrices for a given country.

- It is not explicitly explained how the vulnerability of certain elements of risk have to be addressed and quantified. In the methodology this is apparently unnecessary, as the risk matrix is essentially filled with a smaller or larger set of scenarios for each type of risk. Each scenario should be identified by a return period which allows its characterization in terms of frequency of occurrence.

- The development of scenarios are coarsely described, but are not systematically addressed. Recent literature on this topic can be found in Scholz & Tietje (2002).
- Scenarios have to identify the impact on society (the potential losses) in a structured way (population, economy, ecology, infrastructure, intangible losses). These losses are not exclusively expressible in monetary terms, but rather in descriptive parameters. A methodology is needed to identify the weights with which the impact of particular components in the overall picture are specified. This procedure is not provided by the BBK methodology and remains an open question.
- The uncertainties of losses given a specific level of hazard are not addressed.

In this report we suggest a solution for the third issue raised above, that is the ranking of potential losses within the framework of a scoring scheme requires decisions about the relative relevance of a particular loss (for instance, reduced hospital capacity after an earthquake), as well as the comparison of different loss components. How should the loss of 30% hospital beds in an earthquake scenario be weighted: - minor, moderate, significant, catastrophic? How would this loss compare with the loss of the fresh water supply for 2 weeks for several communities? As a general scheme in addressing these questions, we refer to the multi-decision analysis framework sketched in the following chapter and propose a specific procedure in chapter 7.

6 Multi-Criteria Decision Analysis

The following chapter is excerpted and summarized from Valentin Bertsch's PhD (2008) thesis on Multi-Criteria Decision Analysis (MCDA) and Multi-Attribute Decision Making (MADM). MADM appears in several forms, the most relevant for our purposes being the Multi-Attribute Value Theory (MAVT), which assumes that the underlying data of the decision analysis are deterministic. This contrasts with Multi-Attribute Utility Theory (MAUT) which provides a formal framework for the modelling and handling of uncertainties. This formal approach comes at the price of a significantly higher level of complexity and the associated limitations in its practical application.

In terms of its practical application, MADM is marked by various characteristics which can be classified as follows:

- Number of decision makers.
- Presence of a moderator/facilitator.
- Underlying data (deterministic, probabilistic); in addition, model uncertainties play a relevant role (French & Niculae 2005).
- Timeframe of a decision.
  Decisions may be operational, technical or strategic, referring to different time scales that may vary between hours, days and years. Within the disaster risk management context, the problems we address are usually static. Therefore, a sequence of characteristics and decisions can be used without considering their temporal variability.

Multi-Attribute Value Theory (MAVT):

As stated before, it is assumed that the preferable decision is to be chosen from a discrete set of different alternatives. MAVT is the analytic approach to support decision makers in finding a solution to a multi-criteria decision problem by means of defining an attribute tree (= a hierarchy of criteria) and the elicitation of the relative importance of the criteria within the tree (Geldermann et al. 2009). In the attribute tree the overall goal is hierarchically structured into lower level objectives (criteria) and on the lowest level – measurable attributes.

The crucial interactive steps in a MAVT-analysis include:

1. The structuring of the problem in an attribute tree.
2. The elicitation of the relative importance of criteria.
3. The aggregation of the information to obtain a ranking of the considered additional alternatives.

The appropriate formulation of the problem represents the first step in solving it (Belton & Stewart 2002). Problem structuring at this step gives an improved understanding of the problem itself and the values and criteria that affect a decision. Problem structuring includes the identification and specification of objectives (criteria), attributes, and decision alternatives. These elements have to be structured in a hierarchical model of criteria.

This structuring process can be handled by a top-down or a bottom-up approach. In disaster risk assessment the structure is basically clear and not a matter of stakeholder interpretation. Thus, a top-down approach relying on the classical structure of risk assessment is the rational and preferable method. The structuring of objectives should be clear and hierarchical (lower-level objectives versus higher-level objectives); they should be exhaustive and non-redundant, but cover the essential items.

Each objective is associated with several attributes that in turn lead to various alternatives. The entire attribute tree should be compliant with the following criteria (Keeney & Raiffa 1976):

- Completeness
  All relevant objectives should be included and the set of attributes completely defines the degree to which the overall objective is achieved.
- Operationality
  Attributes should be meaningful and assessable.
- Decomposability
  Attributes should be independent that is it should be possible to analyse one attribute at a time.
- Non-redundancy
  The set of attributes should be non-redundant in order to avoid double counting of consequences.
- Minimum size
  The set of attributes should be as small as possible to ease handling.

Preference elicitation:

After structuring a MADM problem into an attribute tree, it is necessary to construct a model that represents the preferences and value judgements of the decision makers. Such a preference model essentially consists of two components (Belton & Stewart 2002, French 2000):

1. A model that rates each alternative against each individual attribute, enabling the comparison of different attributes on a common scale.
2. A model that allows comparisons amongst the different criteria, which in a subsequent step enables an overall ranking of the alternatives to be obtained.

Thus, before the alternatives can be compared to each other with respect to more than one attribute at the same time, all scores need to be mapped through a common scale ranging from 0 to 1 by utilizing a value function. This value function can have several forms, such as a linear function, an exponential function or a continuously increasing function (Bertsch 2008).

The determination of the form of the value function is important and forms different from the linear one must be considered if the differences between the outcomes of the alternatives are significant.

The second component of the preference model refers to the elicitation of the relative importance between the criteria, and thus evaluates the objectives. As all criteria will play a role, this evaluation is done by weights which are defined such that their sum is equal for all objectives. There are several ways to develop this weighting scheme (Edwards & Barron 1994, Barron & Barret 1996). A particularly attractive approach is the Analytic Hierarchy Process (AHP) (Saaty 1980) which provides a fixed pair-wise comparison procedure which includes redundancy and thus allows the estimation of the consistency of the process.

Aggregation:

The elicitation and modelling of preferential information is followed by aggregating the performance scores with respect to the individual criteria or attributes to an overall performance score taking into account the dates and the value functions. The most common procedure for this is the additives aggregation rule, which evaluates the overall value function by summing the individual value functions with the respective weights. The advantage of this form is that it is easily explained and understood by decision makers.

Sensitivity analysis:

Sensitivity analysis plays an important role in decision making, because the preference parameters in a MAVT analysis are always subjective. The basic process involves varying the preference parameters over appropriate ranges, which will then show how sensitive the overall outcome is to particular parameters. In addition to a sensitivity analysis that relates the performance score to a variation of preferential parameters spider diagrams are typically used for the visual comparison of several alternatives with respect to the different criteria (Vetschera 1994). A spider diagram thus provides a realistic overall impression of the key parameters that influence the decision problem.

7 Loss Index Indicators (LII)

As indicated at the end of chapter 5 we propose a decision making methodology for ranking and scoring of losses in the context of risk mapping following the risk matrix approach. Ranking of potential losses within the framework of a scoring scheme requires decisions on the relative importance of a particular loss (for instance, reduced hospital capacity after an earthquake) as well as the comparison of different loss components. In this chapter, we describe elements of a methodology that addresses the risk matrix decision approach in a coherent and transparent way. The required decisions have been discussed in the previous chapters and are summarized in Fig. 3.

The methodology builds on what was originally developed for the Inter-American Development Bank (IADB) and is called the indicator program. This program is supposed to develop sets of indicators for disaster risk assessment and management. (Cardona 2004, Carreno et al. 2005). One of the indices, the urban disaster risk indicator (UDRI), identifies a scale factor (called the aggravating factor by Cardona, 2004) for the estimated (usually in monetary terms) physical risk. This factor results from mostly social vulnerabilities that are difficult to quantify in financial terms. This method, specifically the development of indicators in stakeholder processes, can capitalise on the ample experience available from a variety of cities and regions of the world (EMI 2009, Fernandez et al. 2006, Khazai et al. 2009).

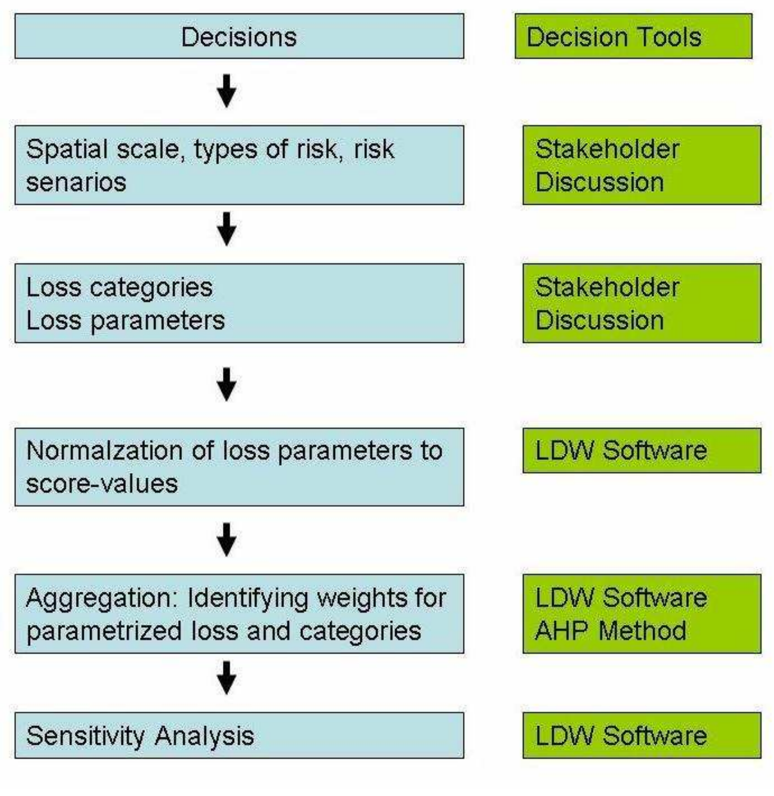

Fig. 3 Decisions incorporated into the risk matrix approach to multi-risk assessment; AHP: Analytic Hierarchy Process, Saaty (1980); LDW: Logical Decisions for Windows Software (http://www.logicaldecisions.com).

The main difference of the adapted LII methodology to the classical indicator approach is that we use indicators for all loss components, irrespective of whether the loss is physical or not, or whether it can be expressed in financial terms or not. Instead of indicators, we call them score-values for various loss parameters.

Comparable to the Cardona (2004) approach, we structure the process into four steps:

(1) Selection of loss parameters
This represents the precise definition and selection of loss components and the parameters with which the loss is expressed for a particular scenario. In the BBK methodology, this includes five major groups of loss types and four subgroups for each of the main types. It is obvious that it can also refer to any other structure of losses. It is mandatory, however, that the set of indicators, and therefore the set of loss components, be comprehensive, non-overlapping, non-redundant, can be clearly described and evaluated, and follows clear definitions and understanding within the stakeholder group.

(2) Normalisation
As for each loss component, the parameter with which the loss is expressed varies. That is, it is necessary to map this parameter to a score-value, e.g. a normalized range between 1 and 5. This step is called normalisation. It essentially consists of the identification and establishment of a function that relates the parameter of loss to the normalized value of the score-value. This function can be linear or non-linear and its selection plays a quite important role. For instance, if the impact of the loss is considered to be fairly linear with regard to the loss parameter, a linear normalisation function would be appropriate. However, in other cases, non-linear functions, for instance exponential functions, must be chosen.

(3) Aggregation
In this step the categories and the score-values within the categories are combined with weights to be chosen by a group of stakeholders in a rational way.

(4) Sensitivity analysis
Due to the difficulty in operationalizing all dimensions of vulnerability (i.e., some dimensions cannot be measured) and the uncertainties in the underlying data, the results might also be affected by different sources of uncertainty. This also applies to the intra-model uncertainties associated with the weighting process and the implementation of transformation functions. In addition, the uncertainties contained within the input-data may be substantial. Therefore, in order to analyse the robustness of the methodology, a sensitivity analysis which demonstrates the variability in the results should be conducted as a final step.

Normalization enables the integration of quantitative and qualitative loss parameters within the same framework. In order for the loss parameters to be commensurate, transformation functions are used to normalize the values of loss parameters into score-values from 1 to 5. The transformation describes the intensity of risk for each one of the score-values. Here, 1 stands for a low loss and 5 for a catastrophic loss. The definition of maximum and minimum values of the loss parameter is important. For the normalization process a multi-criteria decision support software called Logical Decisions for Windows (LDW) facilitates the selection of transformation functions and the calculation of standardized indicator values. LDW uses two types of transformation functions: linear and exponential. The software allows the user to interactively define maximum and minimum ranges, as well as change the shape of the transformation function.

In the aggregation step, the overall score-value is calculated by aggregating the values of the weighted loss categories and loss parameters. An especially important aspect for the quality of results of the integrated indicator system is marked by the assignment of weights for the individual indicators. In the following, N refers to the category of loss: Population (P), Economy (E), Ecology (F), Infrastructure (I) and Intangibles (J):

$$N \in \{P, E, F, I, J\}$$

Within each category there are several loss parameters (in the BBK case, always 4), the number of which is in general denoted as K_N. Each of them has a score-value attached by the normalization process of s_k^N. Within each category, N is the contribution of each loss parameter to the score of this category S^N, is determined by weights w_k^N, defined in the following and determined in a stakeholder assessment approach:

$$0 \le w_k^N \le 1$$

$$\sum_{k=1}^{k=K_N} w_k^N = 1$$

$$S^N = \sum_{k=1}^{k=K_N} w_k^N \cdot s_k^N$$

In a second step, the scores of the loss categories N are combined by a additional set of weights, defined in the following and determined in a stakeholder assessment approach:

$$0 \le W_N \le 1$$

$$\sum_N W_N = W_P + W_E + W_F + W_I + W_J = 1$$

So that the total score of a scenario emerges as

$$S = W_P \cdot S^P + W_E \cdot S^E + W_F \cdot S^F + W_I \cdot S^I + W_J \cdot S^J$$

Value S is then inserted into the risk matrix.

As an example, we assume an earthquake scenario and consider the loss category $N = 4$ (infrastructure) that is, according to Table 1, characterized by $K_4 = 4$ loss parameters (fresh water, energy, gas, communication). A stakeholder analysis of the losses of this particular scenario provided the 4 scoring values (ranging between 1 and 5) as shown in Table 2, which also explains the rationale for choosing the scores. As the severity of the four infrastructure losses are not equal, different weights are attached, ranking the loss of energy as most severe, about 5 time more relevant than loss of public communication and 2.5 times more important than fresh water or gas supply.

Table 2 Example of scores and weights generated by stakeholders for the loss parameter ‘infrastructure’.

Loss parameter	Parameter-index	Score between 1 and 5	Reason for score	Weight of loss parameter (stakeholder)
Fresh water	1	$s_1^4 = 2$	Little damage, restoration within 24 hours.	20%
Energy	2	$s_2^4 = 4$	Several GW knocked out, blackout for several days.	50%
Gas	3	$s_3^4 = 2$	Little damage, restoration within 24 hours.	20%
Communication	4	$s_4^4 = 1$	Excess demand for communication but only minor (hours) disruptions.	10%

Without (stakeholder defined) weights, each parameter would be equally weighted with 0.25 and result in:

$$S^4 = 0.25 \cdot 2 + 0.25 \cdot 4 + 0.25 \cdot 2 + 0.25 \cdot 1 = 2.25$$

With (stakeholder defined) weights the score for category 4 losses would be much higher as the loss of energy supply is considered as very relevant:

$$S^4 = 0.20 \cdot 2 + 0.50 \cdot 4 + 0.20 \cdot 2 + 0.10 \cdot 1 = 2.90$$

We now assume that for the earthquake scenario, the other 4 loss categories have been analyzed and are assigned with a category score value, as shown in Table 3. The 5 loss categories are generally not of equal importance and could be ranked using weights. For instance, the human losses have the highest weight; about 5 times higher than economic losses and 10 times higher than environmental losses, whereas infrastructure losses also qualify fairly highly (see Table 3, where the rational for weights is briefly stated).

Table 3 Example of category scores and category weights.

Loss category	Loss category index	Category score value	Category weight	Reason for category weight
People	1	$S^1 = 1.5$	$W_1 = 50\%$	Highest constitutional value
Economy	2	$S^2 = 2.9$	$W_2 = 10\%$	Not extremely relevant as always small compared to GDP
Environment	3	$S^3 = 1.8$	$W_3 = 5\%$	Small influence attributed
Infrastructure	4	$S^4 = 2.9$	$W_4 = 30\%$	High relevance for impact and reconstruction
Intangibles	5	$S^1 = 2.0$	$W_5 = 5\%$	Small influence attributed

Without (stakeholder defined) category weights, the overall score would be:

$$S = 0.20 \cdot 1.5 + 0.20 \cdot 2.9 + 0.20 \cdot 1.8 + 0.20 \cdot 2.9 + 0.20 \cdot 2.0 = 2.22$$

With (stakeholder defined) category weights, which includes the high rankings for people and infrastructure, the overall score would be:

$$S = 0.50 \cdot 1.5 + 0.10 \cdot 2.9 + 0.05 \cdot 1.8 + 0.30 \cdot 2.9 + 0.0.5 \cdot 2.0 = 2.10$$

As the LDW software uses hierarchies to organize the indicators and sub-indicators, it is possible to visualize the rankings at the highest level (e.g., the ranking of impacts from all the participating hazard scenarios) or at the lowest level (e.g., the ranking of losses for different population loss indicators for one hazard scenario).

Several weight assignment methods are available in the LDW tool which can be used interactively with stakeholders to validate the weights assigned to the indicators. In particular, the Analytical Hierarchy Process (AHP) provides a robust method for weight assignment, as weights are not defined explicitly, but computed from a matrix of pair wise comparisons. The AHP process asks the user to enter more performance ratios than are strictly necessary to compute a set of weights. Because of this, performance ratios are likely to be inconsistent. To provide guidance on the consistency of weight assignments by a user, the developers of the AHP method suggest using a statistic called the Consistency Ratio (C.R.). The C.R. compares the matrix to a random matrix of the same size. The higher the C.R. the more inconsistent the weight assignments are. The developers of AHP suggest that if the C.R. for a matrix is greater than 0.1, the user should adjust ratios to make them more consistent. Two intermediate statistics are used to compute the C.R. The first is called the Lambda-Max (l-max), and is the principal Eigen value of the AHP matrix. l-max is the matrix product of the AHP matrix and the vector of the (unadjusted) weights or utilities for the matrix. The second intermediate statistic is called the Consistency Index (C.I.), which is an absolute measure of consistency and can be computed from l-max.

Another objective in the data analysis phase is to investigate the sensitivity and stability of the various indicators according to the input data, their related weights and transformation functions. Once the importance weights are evaluated, the analysis will look into what subset of factors account for most of the total output variance and pinpoint the non-important factors of the local data. The shape of transformation functions and their effect on the total output variance should be evaluated. The loss parameters should be analysed in terms of their interactions, correlations and causal relationships. This aims not primarily to reduce the number of loss parameters, but at the optimization of relevant risk information input by stakeholders.

8 Summary

MATRIX aims to develop new methodologies for multi-risk assessment for natural disasters. At the same time a political/administrative process has been launched at the EU-level aiming at the harmonization of national risk assessment schemes within Europe (Commission Staff Working Paper. Risk Assessment and Mapping Guidelines for Disaster Management, Brussels, 21.12.2010, SEC (2010) 1626 final) that relies on the classical risk matrix approach. This approach has been developed into a formal methodology, for instance by the Federal Office of Civil Protection and Disaster Assistance (Bundesamt für Bevölkerungsschutz und Katastrophenhilfe – BBK) in Germany as a model, which will be further developed and applied to German risk assessment. This type of risk assessment essentially relies on the development of a risk matrix for different risk types in terms of frequency and severity by the design of many scenarios.

It is the intention of this paper to (a) review – in a general sense – decision models, but more importantly to analyse how the risk matrix approach – in the specific form of the BBK methodology – can benefit from recently developed decision methods (DM). The essential methodological components of the multi-risk assessment process in Europe, on national scale, are defined in the Commission Staff Working Paper “Risk Assessment and Mapping Guideline for Disaster Management”. This methodology includes a specific set of loss components (population, economy, ecology, infrastructure, intangibles) with four subgroups to each main component, based on the decision model of the multi-attribute value theory (MAVT).

Rather than finding a selection process for the best decision, the methodology builds on the experience developed with the disaster risk indices originally designed by Cardona (2004), and widely applied to various cities and administrative units around the world. From a theoretical line of thought and practical experience, we have designed a decision model for multi-risk assessment, predominantly designed for the national scale, as anticipated in the European process. However, this procedure can be easily utilized for different scales, such as communities, regional entities, cities, etc., as long as the risk assessment approach as favoured here is utilized.

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