A Standardized Methodology for Managing Disaster Risk – An Attempt to Remove Ambiguity

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Abstract: A major natural disaster can result in serious damage to buildings and infrastructure, in loss of life and in various other harms to the affected region. Earthquakes, floods, storms as well as their immediate aftermaths such as fires are among the most disruptive natural disasters that occurred worldwide in the last century. Even though the miscellaneous catastrophes are very different in nature and imply various impacts on the affected surrounding area, the general approach to assess, compare and treat disaster risk is quite similar. It is best done on basis of a probabilistic risk management framework that is developed and discussed in detail in this article. With respect to the many different definitions of disaster risk and an inhomogeneous understanding of the risk defining terms in literature, this paper is a contribution to create a unified language as a basis for communication among stakeholders.
1 Introduction

The application of risk management throughout several disciplines and for various perils has led to the development of a great diversity of risk management definitions and methods within the scientific community. Areas of application include finance, medical science, insurance industry, mechanical engineering as well as disaster management. Even within the latter so far no consistency in the risk management terminology has been achieved as the miscellaneous catastrophes, such as earthquakes, storms or floods are very different in nature and cause various harms to the affected region. The many existing definitions for similar principles within the risk management processes often result in confusion. Especially when it comes to interdisciplinary co-operations, an inhomogeneous understanding of basal terms might impose problems in communication. Moreover, different definitions as well as ways to estimate and evaluate risk frequently lead to results, which are not comparable as the underlying range of consequences, that is included in the calculation, is quite uneven. Therefore, costly risk studies often do not provide sufficient assistance to decision makers and accordingly, huge mistakes can be made. As a result, a unified methodology to define and to calculate risk throughout various disciplines is indispensable for a rational quantification, comparison, and treating of risks. Only in this way an effective expenditure of a societies resources into risk reduction can be guaranteed and thus, an adequate safety level obtained.

This article is a contribution to approach these tasks. It provides reasonable definitions and a standardized language for communicating and managing risk among stakeholders. To do this in a justifiable manner, firstly risk definitions and concepts existing in literature are reviewed and out of these, classes of risk calculation schemes are extracted. Subsequently, an exhaustive risk management concept is presented that covers the whole risk management chain, starting from risk identification over risk assessment up to risk treatment. The discussion of the risk management workflow is accompanied by delineating the repeated occurring basal risk terms and illustrating their interrelations graphically. Eventually, the risk calculation schemes are integrated in the concept and their advantageousness with respect to different application fields are discussed.

2 Definitions of disaster risk – A literature review

The analysis and management of natural disaster risk is a high multidisciplinary field of research. It involves the work of natural scientists to determine the hazard characteristic parameters such as probability of occurrence and intensity of an event for a special location, followed by a profound engineering analysis about the building structure and infrastructural responses due to natural disaster loads. Moreover, investigations of economists are needed to estimate the monetary consequences of the damages and harms to the affected region, resulting in a political discussion about how to handle the peril in order to guarantee an adequate safety level for society. This necessity to consider disaster management from the perspective of a great variety of sciences has led to the development of various quantitative as well as qualitative approaches towards disaster management. Each field is trying to cultivate their own understanding of disaster related terms. As a result, commu-
nication within the disaster management community is often accompanied by misunderstandings and confusion due to colliding definitions and concepts. Therefore, a homogeneous understanding of disaster management is crucial for an efficient coordination of the important sub-steps and collaboration throughout the various disciplines. Due to this problematic an extensive literature review has been performed. In the following, exemplary definitions of risk are provided to demonstrate the wide range of definitions existing in literature.

- “The risk is associated with flood disaster for any region is a product of both the region’s exposure to the hazard (natural event) and the vulnerability of objects (society) to the hazard. It suggests that three main factors contribute to a region’s flood disaster risk: hazard, exposure and vulnerability.” Hori et al. [9]

- “Risk is the product of hazard (H) and vulnerability (V) as they affect a series of elements (E) comprising the population, properties, economic activities, public services, and so on, under the threat of disaster in a given area” Alexander [1]

- “The probability of harmful consequences, or expected loss of lives, people injured, property, livelihoods, economic activity disrupted (or environment damaged) resulting from interactions between natural and human induced hazards and vulnerable conditions. Risk is conventionally expressed by the equation: Risk = Hazard x Vulnerability.” UNDP [13]

- “Risk is the probability of an event multiplied by the consequences if the event occurs.” Einstein [4]

- “A combination of the probability or frequency of occurrence of a defined hazard and the magnitude of the consequences of the occurrence. More specific, a risk is defined as the probability of harmful consequences, or expected loss (of lives, people, injured, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human induced hazards.” Europ. Spatial Planning Observ. Netw. [5]

- “Risk is an expression or possible loss over a specific period of time or number of operational cycles. It may be indicated by the probability of an accident times the damage in dollars, lives, or operating units.” Hammer [8]

Out of these citations basically five widespread classes of definitions of disaster risks can be extracted and are categorized subsequently:

1. risk = hazard x vulnerability x exposure
2. risk = hazard x vulnerability
3. risk = probability x consequences
4. risk = probability x loss
5. risk = probability x damage
These risk formulae as well as the exemplary verbal definitions make clear that the different understandings of the term risk are mainly caused by the diverse meanings of the terms hazard, vulnerability, exposure, damage and loss. Obviously, the definition boundaries are blurred and intersecting between the authors’ grasps. Therefore, there is the need to clearly clarify what is understood by each term. Furthermore, it is evident throughout the definitions that no clear formula is used to define the risk. Whereas some authors define risk as a product of several terms, others even avoid any mathematical deepness by simply arguing that risk is a function of several expressions. This observation has also been made Thywis- sen [12], that even goes a step further in arguing “Risk is seen as a function of hazard, vulnerability, exposure and resilience, while the mathematical relationship between the variables is unknown”. In this sense also the above collected risk formulae (1)-(5) are not to be understood too mathematically, but rather illustrative to emphasise the composition of disaster risk. The only clear mathematical formula to quantify risk, that is known by the authors, is the PEER equation for earthquake risk that is provided in Baker et al [3].

In the next section a fully developed disaster management methodology is presented that clearly outlines the important sub-steps of risk management and supplies unambiguous definitions of the risk defining terms. After this has been introduced, the theoretical background is sufficient to demonstrate how the above listed definitions interrelate and can be included in the framework.

3 Proposed risk management framework

The proposed risk management framework that is presented in this section has been developed in close correlation to Pliefke et al. [10] and is structured in compliance with AS/NZS 4360 [2] that defines a risk management process as the:

“Systematic application of policies, procedures and practices to the task of identifying, analysing, evaluating, treating and monitoring risk.”

![Fig. 1: The general risk management framework](image)

As illustrated in Fig. 1 the three main components of the framework are given through risk identification, risk assessment and risk treatment and are performed sequentially throughout the risk management process, accompanied by a risk review step and continuous risk monitoring. The risk review process is assigned to the task to constantly include all new
information, knowledge and experience about the risk and to indicate its evolution within the process over time. Thus, the risk is updated on a regular basis. It should be emphasised that the risk review process is only performed for risks that have already run through the whole process at least once. Consequently, in each risk review iteration the effectiveness of possibly implemented risk reduction interventions is indicated. The risk monitoring procedure in contrast, captures the exchange of information of all persons actively or passively involved or participating in the risk management process. This exchange of information is necessary to guarantee a smooth collaboration between interdisciplinary researchers and to discover new hazards due to the ever changing environment.

3.1 Risk identification

The prerequisite for performing the risk identification phase and therefore to initiate the operation of the risk management chain is the condition of being aware of a dangerous situation. If this is done, first of all the boundaries of the model domain have to be circumscribed by defining the system under analysis. The system can be composed of a single building or infrastructure element, a city, a region or even a whole country. Next, sources of events that are able to endanger the functionality of the system have to be identified and are characterized by the term hazard. Thus, the risk identification step leads to an answer to the question “what can happen and where?” As soon as this analysis is completed for a particular location, it is proceeded with the risk assessment phase.

3.2 Risk Assessment

After having outlined the model domain and identified all possible hazards to the system, the risk assessment phase starts to operate, representing the first crucial step of the risk management framework. The risk assessment itself consists of two sub-procedures, the risk analysis and the risk evaluation module, whose tasks are to be seen in quantifying the risk and comparing it to other competing risks, respectively.

3.2.1 Risk analysis

The risk analysis procedure (depicted in Fig. 2) represents the most sophisticated part of the risk assessment phase, whose major objective lies in the quantification of the risk defining parameters and finally the risk itself, most desirably in monetary units per time unit (i.e. $/year). In order to reach this ambition, first of all a hazard analysis is being performed where the intensity and frequency parameters of each identified hazard type with respect to the predefined system are estimated. Once the hazard data are quantified, it has to be analysed, which components of the system are exposed, i.e. potentially endangered by the impact of the hazard. In this way, a subdivision of the system into elements at risk (EaR) and elements at non risk (EaNR) is performed, depending on the hazard under consideration. As the EaNR are by definition not exposed, they are not threatened by the hazard and can therefore be excluded from the further analysis. An EaR on the contrary, represents a building or another arbitrary infrastructure element that is characterised by several parameters that have to be determined. Among these are precise location parameters within the system, information about the functional use (residential, commercial, industrial), occu-
pancy (inventory of contents, number of people living or working inside) and construction type (building material, number of stories, construction year). A detailed discussion about the EaR parameters is provided in Grossi et al. [7]. Furthermore, to facilitate the analysis, EaR with similar characteristics can be grouped together into EaR classes, depending on the hazard under consideration. Then, the further analysis can concentrate on one typical representant out of each EaR class, assuming that all other EaR of the same category will show similar behaviour.

After all the EaR (classes) have been identified and clearly delineated, the structural behaviour of each EaR (class) has to be predicted depending on the hazard load. The damage module of an EaR is strongly dependent on the structural response of the EaR and captures the physical harm only. It can be expressed by a large variety of measures, e.g. water height, crack width, storey drift, which are used to derive damage states. It has to be clearly emphasised that damage is not measured in monetary values. The relation between the hazard intensity and the resulting damage is called structural vulnerability. Thus, the structural vulnerability is an EaR (class) specific characteristic that indicates the degree of physical susceptibility towards the impact of the hazard.

Subsequent to the prediction of the structural behaviour of all EaR (classes), the consequences for the system that might go in line with a given level of damage of the exposed elements have to be analysed. For this investigation the characteristic parameters of each EaR (class) have to be taken into account. It is distinguished between direct consequences, that occur simultaneously to the time the disaster takes place and indirect consequences, that occur with a time shift as a result of the direct consequences. Whereas direct consequences are in a straight line linked to the coping capacity of the system, i.e. the ability to withstand the natural forces and to provided immediate help, indirect consequences are linked to the resilience, i.e. the capacity to remain functional and recover from the disaster. In addition, each consequence class is further subdivided into tangible or economic consequences, that are directly measurable in monetary terms and intangible consequences, that are not directly appraisable, e.g. injuries and fatalities, pollution of the environment, loss of cultural social and historical values etc. Fig. 2 provides an overview of the consequence division.

Fig. 2: The risk assessment phase
After all possible consequences for each EaR (class) and thus for the system have been determined, loss appraises and eventually accumulates all direct and indirect consequences at the time the disaster takes place. In this respect, the indirect consequences that occur later in time have to be discounted on basis of a properly defined discount rate that is specific for each consequence class. In this context, system vulnerability is an EaR (class) specific characteristic, that links the hazard parameters directly to the loss and indicates the total potential the hazard has on the EaR (class). Thus, it indicates the physical susceptibility of the EaR (class) itself, its contents as well as the resulting degree of disruption of its functionality within the system. Consequently, the structural vulnerability is included in the broader concept of system vulnerability.

The risk analysis phase terminates with the quantification of risk where all the previously collected information is comprised. It is distinguished between two different types of risk. Firstly, risk can be calculated by taking the product of the annual probability of occurrence or exceedance of the hazard or damage multiplied by the expected damage that goes in line with it.

\[
\text{Structural Risk} = \text{Probability} \times \text{Damage} \quad \text{[Damage measure / year]}
\]

It is being referred to as structural risk. Evidently, the structural risk is of primary importance for engineers in order to predict the behaviour and the response of a structure or structural element under potential hazard load. The second way to express the risk is to take the product of the annual probability of occurrence or exceedance of the hazard or loss and the expected loss.

\[
\text{Total Risk} = \text{Probability} \times \text{Loss} \quad \text{[Loss unit / year]}
\]

It is being referred to as total risk. The total risk may comprise all consequences, both tangible and intangible, if a reasonable way has been found to convert the primarily non appraisable harms into monetary units. Alternatively, this transformation of intangible outcomes does not need to be done and the total risk can be split according to the respective consequence classes to indicate their relative contribution to risk. In any case the total risk is more exhaustive than the structural risk as the full hazard potential to the system is taken in account.

### 3.2.2 Risk evaluation

Subsequent to the termination of the risk analysis procedure, the risk evaluation phase is initiated. The purpose of risk evaluation is to make the considered risk comparable to other competing risks to the system by the use of adequate risk measures. In this context, so-called exceedance probability curves have found wide acceptance as a common tool to illustrate risk graphically. In an exceedance probability curve the probability that a certain level of loss is surpassed in a specific time period is plotted against different loss levels. Hereby, the loss to the system can be specified in terms of monetary loss, of fatalities or of other suitable impact measures. An insightful overview of common risk measures and tools to compare risks is provided in Proske [11]. Finally, after having analysed the risk on basis of adequate risk measures, it may be graded into a certain risk class, depending on individual risk perceptions.
3.3 Risk treatment

After the risk to the predefined system has been analysed and graded into a risk class, the last procedure of the risk management framework, the risk treatment phase, begins to operate. This procedure is assigned to the task to create a rational basis for deciding about how to handle the risk in the presence of other competing risks. Based on several analytical tools from decision mathematics, economics and public choice theory, a decision whether to accept, to transfer, to reject or to reduce a given risk can be derived. In the latter case, risk mitigation initiatives are implemented. Fig. 3 visualises the process of risk treatment schematically.

If the risk is to be mitigated, decision makers are able to choose among several opportunities to implement a risk reduction project. All the possible risk reduction strategies have in common that they reduce the vulnerability of the system. Depending on the specific strategy that is chosen, they can either reduce structural vulnerability by increasing the resistance of structures or system vulnerability by strengthening the system to recover from the disaster as quickly as possible. The strategies are subdivided with respect to the time the risk reduction project is implemented.

Firstly, so called pre-disaster interventions, such as prevention and preparedness, are available. Prevention includes technical measures like structural strengthening, that are to be performed with an accurate time horizon before the disaster takes place. Typical examples are dykes against floods or dampers against dynamic actions. Preparedness in contrast contains all social activities, e.g. evacuation plans and emergency training, that are necessary to limit harm shortly before the disaster takes place.

Secondly, post-disaster strategies can be pursued to reduce the risk. Among these, response covers all activities that are performed immediately after the occurrence of the disaster, such as the organisation of help and shelter for the injured and harmed as well as the coordination of emergency forces. Recovery on the contrary, subsumes all activities that need to be taken until the pre-disaster status of the system is restored again.

Obviously, also a combination of the mentioned possibilities can be applied to mitigate the risk. Eventually, for clarity reasons, Figure 4 reviews the entire risk management framework schematically.
Evaluation and integration of most common definitions

After the general risk management framework has been introduced in the last section, at this point it is discussed, how the risk definitions of section 2 are to be seen in relation to each other. Even if the referenced authors might have had different understandings in their risk characterisations, it is shown now, how the diverse formulae can be retraced in the above described methodology. This ambition is approached, by taking the previously established basal terms and definitions as a baseline for argumentation. In the following, the review of the risk Def. (1)-(5) is separated in two passages with respect to the affinity of formulation.

The first two formulae (1) and (2) have the hazard and the vulnerability module in common, while Def. (1) contains an additional exposure multiplier. Therefore, Def. (1) is better suited for the analysis of entire systems, that are composed both of endangered objects (EaR) and non endangered objects (NEaR) that are distributed unevenly within the system. Consequently, the exposure term has to be included in the definition in order to first identify the exposed elements for which the further analysis is being performed. Def. (2) on the contrary is superior in application for risk analysis of one single structural element, where
the exposure to the impact of the hazard is a prerequisite for initiating the investigation. In this case, risk is sufficiently described by the product of hazard times vulnerability. In both definitions of risk it is to be specified case specifically whether structural vulnerability or system vulnerability is employed to calculate the risk. If structural vulnerability is taken into consideration, formulae (1) and (2) are conceptually identical to Def. (5), as structural vulnerability links the hazard to the damage state of each exposed element of system or the single EaR respectively. If system vulnerability is used instead, Def. (1) and (2) are analogous to risk formula (4) as system vulnerability connects the hazard module directly to the loss of the system or the single EaR, by incorporating all direct and indirect consequences that might go in line with the disaster and transforming them to the time the disaster takes place.

Secondly, risk Def. (3)-(5) are considered jointly as they differ in their understanding of hazard outcome, while they have the hazard impact implicit in their probability multiplier. There are basically two ways to interpret the probability multiplier. On the one hand it can refer to the probability that a hazard occurs, while on the other hand the probability of an adverse outcome, specified in terms of consequences, loss or damage could be meant. The variation in the outcome term in contrast, is directly related to the depth of investigation as well as the width of demonstration.

In this respect, the use of the term consequence in Def. (3) is most general and makes a detailed listing of the diverse harms to the system necessary. The depth of analysis cannot be judged upon on basis of the formula. It can either finish with the determination of the physical harm to the considered system or include the total spectrum of adverse outcomes over time. Therefore, formula (3) is most suitable to be applied in political decision processes as in this area, it is essentially to know which parts of the system are especially endangered by the hazard and to which extent. With this information specifically tailored risk reduction interventions can be implemented to guarantee an adequate safety level throughout the population.

The use of loss (Def. (4)) and damage (Def. (5)) as an outcome measure however, usually entails an evaluation of the consequences on basis of a suitable impact measure, and differ in the depth of analysis. If loss is taken into account, it is implicit in the definition that all possible consequences, both direct and indirect, need to be considered and evaluated, dependent on their occurrence in time. Hereby, the loss can either be subdivided by consequence classes, so that it is distinguished between economic loss, loss of life etc., or accumulated in one single number, which entails finding a common scale of evaluation for both tangible and intangible consequences. The use of loss as an outcome indicator is predominantly advantageous in economic considerations, where it is important for instance to express disaster risk as a percentage of national income. Furthermore, on a loss basis it can be judged on the effectiveness of risk reduction interventions, as the benefits in terms of reduced loss can directly be incorporated in cost-benefit analysis. Also in insurance industry it is essential to rely on loss in the calculation of premiums for disaster insurance.

Finally, if damage is taken to convey the outcome, the consideration will be restricted to the physical harm of the elements of the system. Only the immediate reactions of the structures are included in the analysis without questioning the aftermaths. Consequently, the expression of risk in terms of damage is of primary importance in civil engineering, to in-
dicate the structural behaviour under hazard load. Based on this consideration, the engineer can decide for instance whether a strengthening measure of a building is necessary to reduce the structural risk.

5 Conclusion

This article demonstrates how widely the definitions and understandings of the term risk can range. Applied across various disciplines and often used in multidisciplinary collaborations, so far no consistency in delineating the borders of disaster risk could be reached. By providing some exemplary risk definitions out of literature and extracting classes of risk calculation formulae, it is shown that the heterogeneity of risk definitions is mainly due to different understandings of the basal terms hazard, vulnerability, exposure, consequences, damage and loss. These terms, that occur repeatedly throughout the diverse risk definitions, are often used interchangeably and so far no clear concept to circumscribe the terms from each other has been developed. This lack of a harmonized concept is addressed by introducing a clear and flexible risk management framework, that provides assistance in analysing, comparing and treating disaster risk. Each step in this chain is precisely defined and graphically illustrated, leaving some range for problem specific modifications. Finally, the initially listed risk definitions are integrated in the concept and their interrelations are shown. It is illustrated how the definitions vary with respect to the object or system under consideration and differ in the depth of analysis as well as the level of detail. To conclude, the question which formula to use depends strongly on the field of application which makes it necessary to emphasise certain aspects of the risk composition. Therefore, none of the risk formulae can be shown to be superior to an other and even less to be universal. However a “communication in the same language” is indispensable for an efficient multidisciplinary collaboration in implementing all the sub-steps of the risk management chain.

6 Literature


