An integrative model of natural hazard risk evaluation

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Abstract

Since risk mitigating measures have to be accepted by society, risk evaluation by lay people has to be considered in risk management. Due to time and financial constraints, it is impossible to gather this information on a case-by-case basis. Therefore, a model of risk evaluation that accounts for the public risk perception and evaluation is suggested.

The perception affecting factors PAF and the objective risk R_{obj} are important for the perception of the risk. For the decision about the acceptance of risk the evaluation criteria EC are relevant. Together, the PAF, the EC and the R_{obj} allow one to predict the accepted risk R_{acc}. According to the different types of human behavior, the model of 'Prospect Theory' is applied to obtain relevant information about the evaluation and acceptance of risk for different types of persons.
Keywords: natural hazard, risk evaluation, risk perception, risk aversion, Perception Affecting Factors PAF, Evaluation Criteria EC, Prospect Theory.

1 A risk-based approach for the management of natural hazards

Dealing with natural hazards has recently shifted away from being hazard-oriented towards a more risk-based approach ('From the avoidance of hazards towards a culture of risk'[1]). Such a modern proceeding comprises, generally, three components (see e.g. [2]):

Risk analysis (see Fig. 1) is the 'process of quantification of the probabilities and expected consequence for identified risks' ([3]). Consequently, it provides information about the extent and frequency of the expected damage and answers the question 'What can happen?' ([2]). In its simplest formulation, the objective risk R_{obj} may be defined as the product of the frequency (or probability) of

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occurrence F of an event and the extent E of the associated consequences, i.e.

$$R_{obj} = F \cdot E \tag{1}$$

Risk evaluation (see Fig. 1) is the socio-political and moral-ethical 'component ... in which judgements are made about the significance and acceptability of risk' ([3]). Therefore it addresses the question 'What may happen?' and produces the information that is needed to determine the acceptability of risks and thus the acceptable residual risk (R_{acc}).

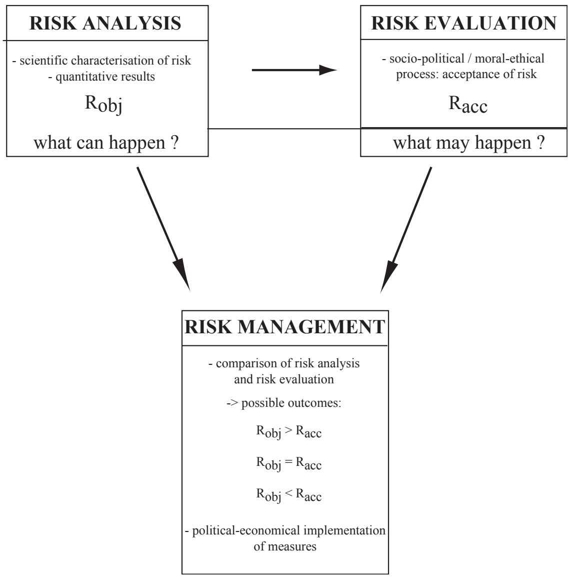

Figure 1: The three steps in a modern risk-oriented approach: risk analysis, risk evaluation and risk management.

Finally, *risk management* (see Fig. 1) aims at reducing risks that are found to be unacceptably high and prevent other risks from becoming so by maintaining a safe state. It combines the results of risk analysis (R_{obj}) and risk evaluation (R_{acc}) in a political process and implements measures based on economic and technical principles ([4]).

This risk-centered orientation is due to economical (increasing marginal cost of protective measures) and environmental reasons (negative environmental impact of the measures) and considers societal concerns about risk.One of the problems associated with this approach is the need for risk managers to make decisions about accepted safety standards. These decisions should be in line with the socioeconomic and moral-ethical preferences of the affected community. This requires that the risk managers have an estimate of the public risk evaluation. In other words,

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risk managers as technical 'experts' must make judgments about the way the 'lay' public perceives risks to account for societal concerns. As this information is usually not available, risk management process generally lacks the methodological competence for evaluating risks. This may result in decisions that conflict with public interests.

2 Current representation of risk evaluation

Currently, two common formal risk evaluation procedures are the approaches of the 'Boundary line' ([5]) and the 'Aversion term' ([6], [7], [8]). Both procedures are based on the same theoretical assumption: risk aversion α, depending on the extent E of the direct damage of an event, is the driving evaluation criteria:

$$\alpha = f(E) = \alpha(E) \tag{2}$$

2.1 Boundary line

The two procedures differ in the way of including aversion. The 'Boundary line' represents constant risk on a double-logarithmic chart (plotting the frequency F and the extent of damage E of events) by a line with the gradient $g(B)$

$$g(B) = \frac{\Delta(log(F))}{\Delta(log(E))} = -1 \tag{3}$$

and risk aversion can be accounted for by changing the slope of the boundary line such that

$$g(B) * \alpha = g^*(B) = \frac{\Delta(log(F^*))}{\Delta(log(E))} < -1 \tag{4}$$

i.e., if the extent of damage doubles, the acceptable frequency is no longer half as high, but usually less than half. This approach is often used in regulatory applications (e.g. the Swiss Ordinance on Technical Hazards [9]). However, it is often not obvious if and to what extent risk aversion has been integrated, however.

2.2 Aversion term

The use of an aversion term (a factor or an exponent in the representation of actual risks, e.g. risk analysis) is an explicit way considering risk aversion. Often, the outcome of this approach is called perceived risk R_{perc}, although only the extent of damage is considered and none of the other factors affecting the evaluation of risk. Consequently, the result should be called 'aversion-corrected risk' R_{AC}:

$$R_{AC} = F \cdot E \cdot \alpha(E) \tag{5}$$

or

$$R_{AC} = F \cdot E^{\alpha(E)} \tag{6}$$

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In both cases, the relations

$$\alpha(E) > 1 \qquad \text{and} \qquad d\alpha/dE > 0 \tag{7}$$

hold, i.e. risks with a greater extent are artificially and progressively increased.

3 Four principles for a new model of public risk evaluation

The origins of the two mentioned risk evaluation approaches are in the field of technical hazards. They provide a wealth of knowledge that can be used in the development of a risk evaluation model for natural hazards. However, it has to be assumed that there are significant differences between the phenomenological characteristics of natural and technological hazards. These differences must be taken into account in the model building process. This process is mainly based on four principles:

1. Mathematical formalization of the evaluation model
2. Correct and complete representation of current knowledge about risk perception and risk evaluation
3. Role and representation of the perceiving person
4. Design for easy implementation and application

4 Implementation of the four principles

4.1 Mathematical formulation of the evaluation model

Under the assumption that the perceived risk R_{perc} does not comply with the objective risk R_{obj}

$$R_{perc} \neq R_{obj} \tag{8}$$

but that R_{obj} contributes to R_{perc}, the perception affecting factors PAF are used to define the perceived risk R_{perc} according to

$$R_{perc} = f(PAF, R_{obj}) \tag{9}$$

The acceptable risk R_{acc} depends on the evaluation criteria EC, i.e.

$$R_{acc} = f(EC) \tag{10}$$

and the decision about the acceptability Acc of a certain risk R_i can now be made according to

$$Acc = \begin{cases} 1 & \text{if } R_{i,perc} \leq R_{i,acc} \\ 0 & \text{if } R_{i,perc} > R_{i,acc} \end{cases} \tag{11}$$

Under the assumption that for a given combination of a risk and its environment i the acceptable risk $R_{i,acc}$ is usually more or less constant, it follows that

$$Acc_i = f(PAF_i, R_{obj,i}) \tag{12}$$

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i.e., the objective risk R_{obj} is not a sufficient basis to judge the acceptability Acc of a risk even if the limits of acceptability R_{acc} are known.

4.2 Current knowledge about risk perception and risk evaluation

4.2.1 Perception affecting factors PAF

An important step in the model development is the determination of i) the relevant risk perception factors PAF driving the perception of risks due to natural hazards and ii) the evaluation criteria EC used for defining the acceptable risk R_{acc}.

The determination of the PAF is based on a survey of perception literature and an adjacent qualitative selection process. The chosen set of factors was submitted to a group of experts from technical, administrative and social institutions dealing with natural hazards. The experts assessed the relevance of the individual factors and the results were compiled. From this procedure resulted a smaller list of factors that was tested on a qualitative basis for collinearity, such that redundant factors could be grouped without significant loss of information (see Tab. 1, left column).

Table 1: List of relevant perception affecting factors PAF. The factors in the column on the right are those known from the literature. *Note:* The suggested selection of PAF is work in progress and subject to change.

Factor	Represents / includes
Voluntariness	
Reducibility	Reducibility, Predictability, Avoidability
Dread	Controllability, Number of people affected, Fatality of consequences, Spatiotemporal distribution of victims Scope of area affected, Immediacy of effects Directness of impact
Experience	Familiarity, Knowledge about risk, Manageability

The next step is the weighting of the relevant PAF considering the following methods:

- Analysis of the risk perception literature in order to gather information about the weighting of several PAF and EC.
- Breakdown of the results of an ongoing risk perception survey in selected Swiss areas (University of Zürich, Sozialforschungsstelle).
- Analysis of current risk evaluation case studies (using the approaches of the ‘Boundary line’ or ‘Aversion term’) in order to gather information about the consistency of the used aversion terms.
- Analysis of pre- and post-event data of case studies regarding the expenditures for the protection of natural hazards in order to gather information about the considered PAF and EC.

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4.2.2 Evaluation criteria EC

As a working hypothesis, it is assumed that the evaluation criteria EC are similar to the PAF, i.e., a factor is not only relevant for the perception of a risk, but also for the limits of acceptability after

$$R_{acc} = f(EC) = g(PAF) \tag{13}$$

From this it follows that

$$EC = h(PAF) \tag{14}$$

Additional criteria according to

$$c \in EC \wedge c \notin PAF \tag{15}$$

will only be defined if this appears to be required for the model building.

4.2.3 Risk aversion

Risk aversion should be taken into account using an improved definition and understanding of it. Not only the extent of direct damage (e.g. number of fatalities or monetary costs) has to be considered but also the indirect effects of a hazardous event (e.g. costs of enacted laws, costs of psychological support of affected people, cost of recovery actions, etc.). Both, indirect and direct effects, can be included in the term *expected consequence* C_{exp}. Furthermore, such an approach must also consider what those affected and the society think about the relevance of these consequences from a sociopolitical, an environmental and an economic point of view.

Based on the consideration of [10] and [11], one can now develop a new definition of risk aversion and an associated concept for estimating its extent (see Fig. 2). Factors or aspects to be included in this approach are:

- Objective risk, particularly the expected extent of consequences (C_{exp})
- Evaluation criteria EC. Since the magnitude of the potential damage is relevant, the scale for judging this magnitude is also important. The aversion against an event i may be stronger than that against an event j even though all the relations $R_{obj,i} < R_{obj,j}$, $R_{perc,i} < R_{perc,j}$ and $C_{exp,i} < C_{exp,j}$ may hold. This can e.g. occur when i results from an involuntary and j from a voluntary activity.
- Effects for the system considered (stability, regenerability).
- Speciality of a risk (extraordinary vs. normal events).

One of the potential pitfalls of such an approach is the mingling of risk perception and risk aversion. Evaluation criteria EC are closely related to the perception affecting factors PAF. A complete delineation between risk perception and aversion is anyway impossible if the validity of the relation $R_{perc} = f(PAF, R_{obj})$ is assumed, since it follows that there is also a relation

$$PAF = g(R_{perc}, R_{obj}) \tag{16}$$

because the processes of perceiving a risk and developing an aversion are influencing each other.

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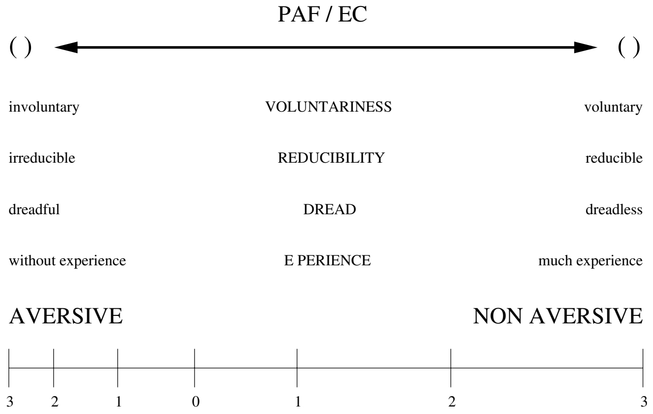

Figure 2: Measuring the aversion means to measure the aversive and an non-aversive components of PAF and EC. The chosen scale has to consider the asymmetric and non-linear character of human behaviour (putting more emphasis on losses than on gains). *Note*: the proposed scale is work in process and an example to highlight a possible solution.

4.3 The role and representation of the perceiving person

The perception of a certain risk also depends significantly on the following factors that have no immediate relation to the risk itself, but to the perceiving person:

- Economic perspectives
- Social environment (structural and cultural properties of the community)
- Values and world views (e.g., technocratic vs. naturalistic, progressive vs. conservative, individualist vs. collectivist)
- Psychological and behavioral characteristics (e.g., risk seeking vs. risk averse)

These factors must be accounted for, but it is probably not possible, and also not desirable, to do so in a ‘parametrized’ way. On the one hand, it is not likely that a useful representation of the individual perceiver can be derived, on the other hand, this is also not desirable because the collective perspective is of interest.

The suggested evaluation model should have as simple a structure as possible and be easily applicable but still allow a causally correct representation of the reality. Thus, the application of a ‘model of human behavior’ seems to be a promising way of integrating the personal factors. A large number of individual risk perception processes can collectively be represented by a prototype behavior.

Due to the fact of the ‘irrationality’ of risk evaluation, a model of man has to be elected that allows modelling human behavior without neglecting all the irrational aspects of it. Therefore, the model of ‘homo oeconomicus’ (realized e.g.in the ‘utility theory’; see. e.g. [12], [13], [14]) is not suitable since it is based on the assumption of full rationality and is characterized by complete information about

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all the relevant decision aspects and a stable and well-structured preference system.

'Bounded rationality' ([14] affords a more comprehensive shaping of the 'irrational' human behavior since it is based on fragmentary and erroneous information about the relevant aspects of a decision and on incompatibilities among different preferences as well as the variation of the preferences system in the course of time.

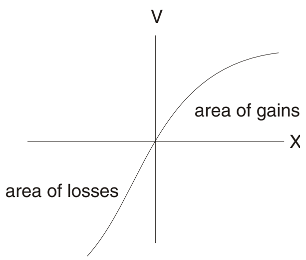

Figure 3: The asymmetric and non-linear value function of the prospect theory puts more emphasis on the losses than the gains.

The innovative work of Kahneman and Tversky ([15]), however, allows a realistic modelling of human behaviour, using a reference point from which the outcome of a decision is evaluated. People usually do not use a value system in order to evaluate an action alternative, but the amount of benefit or loss due to a decision for a specific action alternative. Within the 'prospect theory' the value of this amount is calculated using the value of the reference point as a basic value (and not using the final state of an outcome). The reference point allows to model two main characteristics of human behavior: i) a variable reference system and ii) a asymmetric and non-linear value function: there is more emphasis on losses (convex value function: loss aversion) than on gains (concave value function; see Fig. 3). This effect has also to be considered in the scale of the aversive and non-aversive effect of PAF and EC (see Fig. 2).

5 Discussion and conclusion

The most critical points in the model development process are the many simplifications and assumptions required to create an applicable model. But there are several issues that warrant more detailed discussion.

First, the idea to derive a normative formulation from social and psychological factors originally derived in a non-normative context and applying this formulation within an engineering context may give raise to questions. However, managing risks involves making decisions, and while it is obvious that a perfect representation of the real risk evaluation will never be possible, one should nevertheless try to improve the basis for the decision making. The goal is not to replace the evaluation process, but to facilitate the selection of 'good' options (i.e., those that are likely to be in line with the evaluation) within the framework of risk management.

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A second issue is the definition of PAF components as suggested above (including their weights and scales). It is obvious that laypersons play a vital role in evaluating risks. They should be represented in the definition of the factors that drive the model. This was not possible due to time and budget constraints. This is a shortcoming of the chosen approach. But this shortcoming will be diluted using the outcomes of a currently ongoing inquiry about the perception of natural hazard risks in affected Swiss regions as an evaluation and calibration tool of the model.

A third issue is the inclusion of risk aversion in the evaluation process. While aversion was the only factor considered so far in formal evaluation procedures, it may almost disappear in a new model since it is expressed by the perception affecting factors PAF and the evaluation criteria EC. This would be a clear change in practice, and it remains to be seen if such a change will be endorsed by the risk management community.

6 Conclusion: the importance of an evaluation model for a culture of risk

In a culture of risk based thinking, decision making must not be limited to 'scientific' findings and methods, but it must also include societal aspects and concerns as brought forward in the evaluation process. As it is usually not possible to directly operationalize and quantify this public evaluation, the decision makers are left with the obligation to consider the evaluation appropriately. Up to now, this has happened in an intuitive and subjective manner, which is unsatisfactory for both the decision makers and the public. A model as suggested above would allow this process to be formalized, ensuring that the public evaluation is taken into account in a consistent manner and at the same time relieving the decision makers from an obligation that most of them did not really seek.

However, while the knowledge about the objective risk R_{obj} and the perceived risk R_{perc} is a valuable input for the allocation of resources, it is by far not the only factor relevant in risk management. Other issues such as the comparison with other risks or regulatory provisions (legal limits etc.) are in reality often at least as important as the socioeconomic aspects that are addressed by risk analysis and risk evaluation results.

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