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Improving risk characterisations in practical situations by highlighting knowledge aspects, with applications to risk matrices

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ABSTRACT

Current practice for risk characterisations is based on methods reflecting threats, their consequences and probability, as well as concepts like risk factors and sources. The risk matrix is an example of such a method. The risk analysis field has demonstrated that there are many challenges related to this practice and there is a substantial potential for improvements in how the characterisations can be conducted. The key is to better reflect the knowledge aspect of risk. The purpose of the present paper is to present a set of practical methods that can be used for characterising risk in this setting in line with these findings of the risk analysis field. Extended risk matrix approaches are highlighted. These approaches include strength of knowledge judgements and rankings of risk factors and assumptions supporting the analysis. Special attention is given to potential surprises relative to the current knowledge. Simple examples are presented to illustrate the use of these methods and approaches.

1. Introduction

Many risk analysts need to address the following problem: How should the organisation describe or characterise the risks that it faces, in a way that is simple and at the same time sufficiently informative for the management and decision makers. The scope could be safety or security related or enterprise-wide, covering all types of risks (strategic, financial and operational risk). See Teng et al. [42,43] for examples of such characterisations for safety/security organizations. Risk matrices are frequently used for this purpose, despite the strong criticism of their use that has arisen (e.g. [6,17,22]).

Underlying risk matrices and other simple ways of describing or characterising risks, is a basic idea that risk can be adequately captured by two dimensions – consequence (referred to as C) and probability (P) – or even by one dimension: the product of these two dimensions leading to the expected value (E). However, in general, this idea can be challenged. Consider the common approach where risk is described by the probability P of an event A, and the expected value of the consequence given the event A, i.e. $E[C|A]$. Hence the risk description covers the pair (P(A), $E[C|A]$). Here A can for example refer to loss of critical personnel or a major accident.

Adopting such an approach, we are ignoring two main aspects of risk:

a) The fact that E[C|A] could be a poor prediction of the actual consequences C given that the event A occurs.
b) The fact that the knowledge K supporting the probabilities could be more or less strong and even wrong (for example erroneous assumptions).

Using unconditional expected values as in $E[C]$, a third aspect is being ignored, namely variations in P(A) relative to $E[C|A]$. We can have two completely different situations, one with low P(A) but high $E[C|A]$, and one with high P(A) but low $E[C|A]$, giving the same expected values. Clearly, to be adequately informed about risk, these situations should not in general be seen as identical [2,26,37].

The risk characterisations are to be used to support decision making, but the risk matrices and similar probability-based descriptions do not cover underlying risk (influencing) factors or sources, such as a cost-efficiency focus in the company and maintenance. The links between such risk factors (sources) and the risk description are better reflected using bow ties and Bayesian influence diagrams; see for example Zio [51], Vose [48] and Meyer and Reniers [35]. From these links it is possible to identify the most important risk factors (sources), which in their turn provide a basis for suggesting measures and in particular risk reducing measures. To make judgements about importance, the above argumentation suggests that we need to see beyond the traditional risk matrix type of approaches. It is also necessary to include judgements related to the knowledge K. How this should best be conducted is not, however, obvious.

The present paper presents a set of approaches and methods meeting the above challenges, the intention being to properly characterise risk,

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giving due attention to the knowledge aspects. Recently, considerable work has been done justifying the need for broader risk characterisations as discussed above (e.g. [6,23]), and some concrete approaches and methods have been suggested (e.g. [3]). The current paper summarises this work and refines and extends the existing results. The practical use of the approaches and methods is highlighted.

There is a huge body of literature on tools for practical risk characterisations, covering different types of risk matrices and risk ranking, rating and scoring systems, which range from simple risk indices to characterisations that also consider other relevant aspects important for decision making, including costs and ethical concerns; see e.g. Morgan et al. [36], Haimes et al. [27], Cox et al. [19], Cox [18], Yu et al. [50], Ball and Watt [11], Ruan et al. [40], and Aven and Cox [7]. However, only a few of these works address the knowledge dimension as discussed in the present paper. Several risk analysis researchers have highlighted the need to see the results of risk assessments in view of the assumptions made (e.g. Beard [12] and Paté–Cornell [37]). However, with respect to broader discussions linking risk with knowledge, there are not so many contributions. There is a considerable amount of literature on sensitivity analysis and uncertainty importance analysis, where the challenge is to identify the most critical and essential contributors to output uncertainties and risk; see e.g. Borgonovo and Plischke [16]. This type of analysis is useful in identifying critical assumptions and risk (influencing) factors, which is a key topic of the present paper.

The paper is organised as follows. Firstly, in Section 2, a framework for the risk characterisations (descriptions) is presented, covering basic features of the risk concept and its characterisation, strength of knowledge judgements, judgements of risk related to deviation in assumptions, importance of risk factors (sources), and importance of measures. This framework is based on general ideas and principles, but is limited to characterisations produced by the risk assessments. Other frameworks exist capturing also the decision making context, as in for example Lambert et al. [33] and Karvetski and Lambert [29]. These works are based on a perspective where the threats deserving of more attention are those that disrupt priorities of an organization, rather than those that are intrinsically "bigger" in risk. Section 3 demonstrates the use of the framework for two examples, the first one linked to risk matrices, and national and global risk characterisations, and the second related to ranking assumptions and risk factors, and selecting suitable measures. Section 4 discusses these examples and related issues, and, finally, Section 5 provides some conclusions.

2. Framework for characterising risk

Think about any type of activity, for example an investment, the operation of a system, the design of a new product, giving a speech, or exploring a new area. Looking into the future, the activity can lead to different consequences (C) in relation to some values such as health, lives, the environment and economic assets. Today we cannot say what these consequences will be; there is uncertainty. These two elements are the two main features of the risk concept: consequences C in relation to the values of interest and related uncertainty (U). There is no universal agreement on understanding risk in this way, but it represents a general perspective on risk, capturing most other common definitions of risk, and it is in line with the definitions and recommendations of, for example, the Society for Risk Analysis [41], ISO [28] and PSA-N [38].

The idea is to make a clear distinction between the concept (here risk) and how this concept is described, measured or characterised, in line with measurement theory [44]. A probability distribution of the number of fatalities, as a result of the activity, is an example of such a risk characterisation. The ways risk can be characterised are many and, in the following section, alternative approaches and methods will be presented and discussed, highlighting the knowledge dimension as discussed in Section 1. The characterisations need to address both C and U; we need to specify C and find ways of representing or expressing the uncertainties. The (C,U) set-up is general and allows for both positive (desirable) and negative (undesirable) consequences. There is always at least one negative consequence (outcome) when talking about risk. An activity is to be interpreted here in a broad sense to also include natural phenomena. The consequences are often seen in relation to some reference values (planned values, objectives, etc.). In a project, the issue of interest could be risk related to not meeting the defined cost target. The consequences C are then to be defined as the deviation between the target and the actual cost, and U relates to uncertainty about this deviation.

2.1. *General theory about risk characterisations*

To characterise risk, a risk assessment is conducted. The characterisations need to meet the needs of the risk assessment and of the decision making the assessment is to support. There are, however, some fundamental ideas and principles to be followed, that are generic and applicable to all types of situations. These we discuss in this paper and in the following sections.

Firstly we address the consequences C. Then we will look at the uncertainties U.

2.1.1. *Describing the consequences C of the activity considered*

In the risk assessment we need to clarify which aspects of the consequences we would like to address. This relates to two main dimensions: i) the values we are concerned about (lives, environment, assets, etc.) and ii) the level of scenario development elements (risk sources, events, barrier performance, outcomes). Examples of these elements for the values lives for a petroleum installation could be maintenance, occurrence of a leakage, the performance of a lifeboat, and the number of fatalities, respectively. A potential risk factor (source) is maintenance, giving rise to a process leakage, which in its turn could result in loss of lives, depending on the presence and performance of various barriers, for example lifeboats. The consequences C cover all these scenario development elements, but often the risk characterisation focuses only on the outcomes: here, the number of fatalities. However, in other cases all these elements are highlighted; for example, this is the case when the authorities present the risk level of the Norwegian petroleum activities [39]. The number of leakages could be more informative than the number of fatalities in many cases, as the latter number is often zero when studying major accidents.

Let C' denote the consequences specified in the risk assessment, capturing the quantities of interest. Similar to C, some components of the specified consequences C' can express deviations relative to some specified goals or targets.

The scenario development can be just a listing of the elements, or it can be based on modelling, using tools such as fault trees, events and Bayesian networks. The modelling means simplified representations of the relationships between the various elements. Let C_1' denote the number of fatalities in the future period studied, and let g(X) express the model used to compute C_1', i.e. $C_1' = g(X)$, where X is a vector of elements. If C_1 denotes the actual number of fatalities, we can identify a difference $e = g(X) - C_1$, which is referred to as model (output) error.

What characterises the above scenario development elements is that they are observable quantities, in the sense that if the activity is realised we can observe the number of fatalities, the occurrence or not of a leakage, etc. In risk analysis we also use unobservable quantities, typically defined as parameters of probability models. A probability model is a model of a phenomenon in the real world represented by means of frequentist probabilities. A frequentist probability of an event A is interpreted as the fraction of times A occurs if we could infinitely repeat the situation considered under similar conditions. A frequentist probability is also referred to as a propensity, a property of the situation considered, which allows for repeated experiments leading to the fraction of events occurring defining the frequentist probability [5].

For example, to model the occurrences of gas leakages, we may introduce a Poisson distribution with parameter (expected value) λ. It is well