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Review

Recommendations on the use and design of risk matrices

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ABSTRACT

Risk matrices are widely used in risk management. They are a regular feature in various risk management standards and guidelines and are also used as formal corporate risk acceptance criteria. It is only recently, however, that scientific publications have appeared that discuss the weaknesses of the risk matrix. The objective of this paper is to explore these weaknesses, and provide recommendations for the use and design of risk matrices. The paper reviews the few relevant publications and adds some observations of its own in order to emphasize existing recommendations and add some suggestions. The recommendations cover a range of issues, among them: the relation between coloring the risk matrix and the definition of risk and major hazard aversion; the qualitative, subjective assessment of likelihood and consequence; the scaling of the discrete likelihood and consequence categories; and the use of corporate risk matrix standards. Finally, it proposes a probability consequence diagram with continuous scales; providing, in some instances, an alternative to the risk matrix.

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1. Introduction

Risk matrices are simple tools to rank and prioritize risk of (generally adverse) events and to make decisions whether certain risks can be tolerated. A risk matrix displays the basic properties, "consequence" and "likelihood", of an adverse event and the aggregate

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notion of risk by means of a graph. It uses discrete categories of consequence, likelihood, and risk. Using categories rather than numerical values has appeal to both risk specialists and laymen as a means of stressing the uncertainties in risk statements. The combinations of consequence and likelihood are mapped on to a limited number of risk categories (often visualized by different colors) and this mapping may include subjective considerations, such as major hazard aversion.

Risk matrices present risk graphically, and belong to the set of probability consequence diagrams as described by Ale et al. (2015).

Risk matrices are referred to in the informative sections of various international standards such as ISO (2002), IEC 60812 (2006), and ISO (2010) and industry sector or national risk management practices, for example (DNV, 2009; Carter et al., 2003; PPRT, 2005).

A paper from BASF (Ruge, 2004) documents how a single risk matrix gains the status of a corporate framework, governing risk management decisions throughout an entire company. Although ISO 31010, in its Appendix B29 (2010), advises that risk matrices should be adapted to each area of application, we have observed that several large companies have developed corporate risk matrices to standardize risk decisions throughout their organization.

The aim of any risk evaluation tool is to ensure that the decision process is transparent, based on best knowledge and reflects the common understanding of stakeholders. When reviewing the application of risk matrices, it becomes obvious that this simple tool has some notable weaknesses. Both users and designers of risk matrices should be aware of these shortcomings and ensure that the risk matrices are used in such a way that correct conclusions are drawn. Only recently have some publications addressed this problem. The first openly critical review was published by Cox (2008) followed by Levine (2012) and Flage and Røed (2012). The mentioned appendix B29 of ISO (2010) also includes an invaluable summary of the advantages and disadvantages of risk matrices, together with recommendations for their usage.

Risk matrices have two main applications. The application or aim of the risk matrix is relevant when discussing the suitability of risk matrices. One application is decision-making about the acceptance of risk; the other is to prioritize which risk needs to be addressed first.

Frequently, in risk acceptance, only three levels of risk are distinguished: hazards or events with unacceptable risk (often indicated with a red color); hazards or events in which the risk is found to be "broadly acceptable", i.e. not requiring further risk reduction (often indicated with green), and an intermediate level, where risk should be reduced "As Low As Reasonably Practicable" (ALARP, often indicated with yellow). Given these interpretations, there is no need to further prioritize hazards, at least not in the red and green areas.

In cases where the risk matrix is used for prioritizing (which hazards require most attention in order to reduce the cumulative risk), a larger number of risk levels may be necessary in order to obtain sufficient resolution to rank events or hazards in order of priority. Even then, different hazards may end up either in the same cell or with the same assigned risk (so called *risk ties*, see (Ni et al., 2010).

At the end of this paper (Section 6) we describe a probability consequence diagram with continuous scales for likelihood and consequence as an alternative to the risk matrix with discrete categories. Such a representation can solve some disadvantages of discrete risk matrices (such as risk ties).

2. Definition of the risk matrix

Risk matrices have been described in many occasions, so this section is limited to a short, formal description in order to support the subsequent analysis.

Risk is often expressed in terms of a combination of the consequences of an event together with the associated likelihood of its occurrence (Note 4 to the definition of risk in ISO (2009)). Statements about risk are statements about possible future situations, and these statements are, by their nature, inherently uncertain. In order to manage this uncertainty in an intuitive way, many risk managers prefer not to assign numerical values to likelihood and consequence, but instead assign discrete categories of consequence and likelihood to the event. As discussed later in this paper (Section 6), this is not necessarily the correct way of dealing with uncertainty. The risk matrix facilitates assigning a discrete risk category to each combination of consequence and likelihood, i.e. it provides a mapping of consequence and likelihood to risk. This mapping may be subjective and is not bound by formal restrictions, though it is natural to ensure that the mapping function is monotonically increasing: an increase in consequence (where likelihood remains the same) or an increase in likelihood (where consequence remains the same) may not lead to a decrease of the assigned risk. The mapping may account for subjective or societal aspects of risk perception, such as major hazard aversion (events with low likelihood yet large consequences are assigned a higher risk than events with small consequences and high likelihood even if the expected loss – expected loss being defined as consequence × likelihood – is the same).

Each pair of consequence category and likelihood category can be assigned a different risk attribute, if there are 'N' consequence categories and 'M' likelihood categories, one can discriminate N × M different, discrete risk categories, see Fig. 1. Nevertheless, it is normal to divide the grid of the risk matrix in areas with fewer categories, often by using colors, such as green, yellow and red, to represent low, medium and high risk, or by deriving a risk score, often an ordinal value, through the combination of consequence and likelihood. This means that different combinations of consequence and likelihood are assigned identical risk: they have the same color or the same risk score. In the remainder of the paper, "coloring", in the sense of assigning a color to a cell in the matrix, and risk scoring, in the sense of assigning a risk score to a cell, will, in most instances, be considered as synonyms.

Risk matrices can be used in two stages: in the first, the potential event (or hazard) is plotted in the two-dimensional grid of the risk matrix according to assigned consequence and likelihood. In this process, even when the grid is divided in a limited number of colors, no information is lost as yet: the viewer can still see how the position of the hazard originates from its consequence and likelihood attributes, see Fig. 2. In the second stage however, the risk (color or score) of the event or hazard is portrayed as a single dimension, and it is here that the mapping of risk really becomes effective and is most significant in influencing decision-making regarding tolerability, or setting priorities.

2.1. Defining risk in the framework of the risk matrix

In the above, risk is defined as the mapping of the two attributes of an adverse event (consequence, likelihood) to some value of risk. In the context of the risk matrix the value of risk is a discrete value, corresponding to the categories of consequence and likelihood: "IF

		Consequence Classes			
		C1	C2	C3	C4
Likelihood Classes	F3	R9	R10	R11	R12
	F2	R5	R6	R7	R8
	F1	R1	R2	R3	R4

Fig. 1. A 3 × 4 risk matrix leads in principle to 12 distinguishable risk categories.