Safety Science 101 (2018) 344–351

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/safety

Discussion

Prediction in a risk analysis context: Implications for selecting a risk perspective in practical applications

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ARTICLE INFO

Keywords:
Foundational issues
Prediction
Risk perspective
Probability of frequency
Uncertainty

ABSTRACT

Recently, there have been several calls for increased attention to foundational issues in risk analysis, addressing issues like terminology, principles and theories. An important foundational issue is the appropriateness of different concepts and perspectives for analyzing risk in practical applications. Several authors have addressed this through arguments involving, inter alia, the definition of risk, the ontology of risk, and the reliability and validity of risk analysis. This paper aims to contribute to this discussion by focusing on the concept of prediction. While this term is quite frequently used in risk analysis contexts, no earlier work has specifically focused on the issue of whether risk analyses can be considered to be predictive, and if so, in what sense. Neither has this been linked to the feasibility of risk perspectives. First, two definitions of what prediction can mean are elaborated, and criteria corresponding to these definitions are outlined to facilitate the subsequent discussion. A brief discussion on system types is included, as one type of prediction is defined through the relation between the model and the modeled system. Then, the definitions of prediction and the corresponding criteria are used to consider the appropriateness of two commonly used risk perspectives, namely the probability of frequency and the uncertainty perspective. In the former, a risk analysis aims at estimating an underlying true risk with quantified uncertainty bounds. In the latter, a risk analysis is a descriptive account of judgments and uncertainties by an assessor. It is finally argued that the uncertainty perspective generally is more appropriate than the probability of frequency perspective for practical risk analysis applications.

1. Introduction

In risk research, there is a recent focus on foundational issues addressing concepts, theories, principles and terminology. The development of well-founded risk perspectives is an important issue to strengthen the theory and practice of risk analysis. A risk perspective can be understood as a commitment to a conceptual understanding and a definition of risk, which results in a corresponding approach to measure/describe risk (Aven and Zio, 2014). Establishing such perspectives is important to support decision making (Kristensen et al., 2006), but also e.g. for validating risk analyses (Goerlandt et al., 2017) and for ensuring successful risk communication (Veland and Aven, 2013).

Several authors have proposed new risk perspectives. Kaplan and Garrick (1981) introduced the probability of frequency perspective, extended by Haimes (2009) with a focus on the time dimension. Aven (2010) introduced the uncertainty perspective, in which uncertainties in the background knowledge for making the probability judgments are explicitly treated. Aven (2013) further extended this perspective to include an assessment of unforeseen events, surprises and black swans. Gardoni and Murphy (2014) proposed a moral perspective, which considers the risk source as a third dimension apart from the probability and consequences.

Subsequent work has developed and discussed practical methods for measuring risk according to the different risk perspectives, see e.g. Szwed et al. (2006) and Zio and Pedroni (2013) for the probability of frequency perspective and e.g. Aven (2013), Goerlandt and Montewka (2015a) and Berner and Flage (2016) for the uncertainty perspective. Other work addressing risk perspectives has proposed a conceptual approach for combining the risk ranking results according to different underlying perspectives (Goerlandt and Reniers, 2017).

Several authors have addressed the adequacy of the proposed risk perspectives in theoretical discussions. Aven (2010) distinguished the probability of frequency and the uncertainty perspective based on

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http://dx.doi.org/10.1016/j.ssci.2017.09.007
Received 23 March 2017; Received in revised form 26 August 2017; Accepted 13 September 2017
0925-7535/

arguments for an uncertainty-based definition of risk. Aven et al. (2011) discussed the ontological status of risk in relation to a series of risk definitions and perspectives. Aven and Heide (2009) presented an analysis of the reliability and validity of risk analysis for a set of risk perspectives, including the probability of frequency and the uncertainty perspective, using a proposed set of reliability and validity criteria. Rosqvist (2010) discussed the issue of validity of risk analysis, focusing on the assessment of biases in probability-based risk perspectives, arguing that a systematic assessment of the direction of bias can give more insights than uncertainty assessments alone. Haugen and Vinnem (2015) have provided critical comments regarding the inclusion of certain interpretations of black swans into uncertainty-based risk perspectives. Rae and Alexander (2017) presented a review of the validity and accuracy of expert elicitations, relating this to different views on risk perspectives in a risk management context.

A question that has not received much explicit attention is whether risk analyses can be considered predictive. In the literature concerning quantitative risk analysis of socio-technical systems, several authors have claimed or implied that this is the case [1]:

> 'The PSA approach aims at defining a comprehensive, integrated model […] in which the predictions […] are performed […]'
> (Zio and Apostolakis, 1996, p. 226)

> 'PRA uses mathematical probability in an attempt to deliver precise predictions.'
> (Crawford, 2001, p. 8)

> 'When a QRA predicts that an accident will occur […]'
> (Rae et al., 2014, p. 67)

Solberg and Njå (2012) argue that due to causal determinism, predictions can be made, but that due to uncertainty and the potential for surprises, these cannot be given any truth-value. Rae et al. (2012) have criticized the view that QRA models make predictions due to lack of scientific evidence. Paté-Cornell (2012) addresses the issue of prediction in the context of black swans, finding that rare events cannot be predicted.

Given the lack of in-depth discussion on prediction in a risk analysis context, the existence of various views apparent from the literature, and the general importance of prediction in scientific contexts (Douglas, 2009; Shmueli, 2010), this paper focuses on this issue. In particular, it is considered if, and if yes, how, risk analysis can be considered predictive. Furthermore, the focus is on the adequacy of the probability of frequency and the uncertainty perspective in light of two definitions of prediction (common and accurate), considering different types of systems. This distinguishes our work from existing literature on the perspectives, which has focused on other issues as outlined above. Our discussion differs from these in two respects, by focusing on the issue of prediction, and by distinguishing different system types.

The remainder of this paper is organized as follows. In Section 2, two possible definitions of prediction in a risk analysis context are elaborated, and corresponding criteria outlined. Section 3 briefly introduces different system types, whereas Section 4 introduced the risk perspectives in focus in this paper, namely the probability of frequency and the uncertainty perspective. In Section 5, an analysis is made of these risk perspectives, in light of the different interpretations of prediction and the considered system types. Section 6 provides a discussion on the appropriateness of the risk perspectives in light of the findings related to the predictability. Section 7 concludes.

[1] The abbreviations PSA (Probabilistic Safety Assessment) and PRA (Probabilistic Risk Analysis) are used as synonyms of QRA. PSA and PRA are primarily used in the nuclear industry, whereas QRA is more commonly applied in the chemical industry.

2. Definitions of prediction in a risk analysis context

As is clear from the introduction, there are different views on whether or not risk analyses are predictive. However, none of the above-mentioned authors explicitly defines prediction in presenting their views. In the recent glossary by SRA (2015), prediction is not defined either. Aven and Zio (2014) argue that conceptual clarity is one of the primary needs to strengthen the foundations of risk analysis, and Johansen and Rausand (2015) find that striving for clear definitions is important to avoiding linguistic ambiguity in risk analysis. Therefore, in this Section, two possible interpretations of prediction in a risk analysis context are presented, including definitions and corresponding criteria.

2.1. Definitions of prediction

Two definitions for understanding prediction in a risk analysis context are distinguished, suggested by Hodges and Dewar (1992). These have been adopted also e.g. in natural science (Oreskes, 1998) and economical science (Scher and Koomey, 2011) contexts.

Definition 1. Prediction (accurate) A prediction is accurate if (i) a statement about an observable or potentially observable quantity or event is produced; (ii) the modeled situation is such that predictive accuracy *can* be measured; and (iii) the predictive accuracy of the model in the situation *has* been measured.

Definition 2. Prediction (common) A prediction is a statement about an observable or potentially observable quantity or event.

In the above, given the focus on prediction in a risk analysis, the phrase 'a statement' is taken to be a description/measurement of risk according to a systematic approach. In risk-theoretic terms, this relates to the adopted risk perspective, which is the totality of elements considered in the risk description and the adopted interpretation of the tools for measuring risk. In Section 4, two such risk perspectives are considered, namely the 'probability of frequency' and the 'uncertainty' perspectives.

It is clear that Definition 1 (accurate prediction) is much more restrictive, but the additional conditions are necessary if one aims to make claims about the accuracy of the statement. Without actually testing the predictive accuracy of the statement, it is an unexamined claim whether an accurate prediction has been produced. Because science requires warrants for claims of accuracy (Douglas, 2009), condition (iii) is included. In turn, if one wants to measure the predictive accuracy of a statement, it has to be possible to do so, because of which condition (ii) is included (Hodges and Dewar, 1992).

2.2. Criteria for accurate prediction

Hodges and Dewar (1992) propose four criteria for a situation to be accurately predictable, according to Definition 1. These are briefly considered next.

CR1. Observability and measurability. The situation being modeled must be observable and measurable. This means that the model should be able to produce specific statements about observable quantities or events, that corresponding measurements should be made in the system, and that the model-produced statements should be compared with these measurements without adjusting the model, its inputs or outputs in this comparison.

CR2. Constancy of structure in time. The situation being modeled must exhibit a constancy of structure in time, i.e. one should have reason to believe that the causal structure of the situation is sufficiently constant so that measurements taken at one time can be reproduced under the same conditions at a later time.

CR3. Constancy across variations in conditions not specified in the model. The situation being modeled must exhibit a constancy across variations in conditions not specified in the model. This means that test measurements are relevant to future situations under which