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Ambiguity in risk assessment

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ABSTRACT

This paper discusses and clarifies the meaning of ambiguity in risk assessment, identifies sources and manifestations of ambiguity in risk assessment, and outlines a procedure for approaching ambiguity in risk-informed decision-making. Existing definitions of ambiguity are reviewed and argued to be of limited relevance for engineering risk assessment. A new overall definition of ambiguity as a challenge to risk-informed decision-making is proposed, and linguistic, contextual, and normative ambiguity are defined as distinct categories of ambiguity. Three tables identify sources and manifestations of ambiguity in preassessment, risk analysis, and risk evaluation. The tables provide the basis for a new procedure for identifying and resolving ambiguity in an analytic-deliberative approach to risk-informed decision-making.

1. Introduction

Ambiguity is a challenge to many strategic decisions that involve major accident risk. The ambiguity may concern what information is needed to inform the decision-process, the basis for providing it, and the meaning and implications for decision-making. According to Slovic (2001), this boils down to ambiguity in the interpretation of *risk*. In most practical risk assessments, risk is defined as the answer to three questions: (i) What can go wrong? (ii) How probable is it and/or how uncertain are we? and (iii) If it does go wrong, what are the consequences? (Kaplan and Garrick, 1981; Aven, 2012). Risk assessment can be defined as the process of defining, answering, and evaluating these questions in the phases of preassessment, risk analysis, and risk evaluation/decision-making. Ambiguity may pervade all three phases, for example, in relation to the definition of scope and boundary conditions, application of risk analysis methods, and formulation of decision criteria (Stirling, 2007).

Klinke and Renn (2002) consider ambiguity as one of three defining challenges that compromise the role and value of risk assessment in risk-informed decision-making (the other two being uncertainty and complexity). Ambiguity is in their view synonymous with social controversy and calls for participatory approaches to risk assessment and decision-making. An example is the analytic-deliberative process of NRC (1996), which means that the assessment should be based on inputs from discussions with decision-makers and stakeholders. There is, however, limited guidance on how to make the ambiguity concept operational in such a setting.

The literature on risk and decision-making provide diffuse explanations of ambiguity. Some associate ambiguity with conflicting values and beliefs about *consequences* (IRGC, 2005; Stirling, 2007) or incomplete knowledge about *probabilities* and *uncertain events* (Bedford and Cooke, 2001; Ellsberg, 1961). Others attribute ambiguity to imperfections in human judgment (Catrinu and Nordgård, 2011; March, 1987). Many definitions are limited to only one or two of the questions in the definition of risk, and are problematic in light of foundational research on engineering risk assessment (Aven, 2012). Little has, to our knowledge, been done to scrutinize the concept of ambiguity in this context, and this indicates that it has not been fully recognized as a challenge in the theory and practice of risk assessment.

The motivation for this paper is that clarifying ambiguity can improve the role and value of risk assessment in risk-informed decision making. The objectives are to (i) clarify the meaning of ambiguity in relation to risk assessment, (ii) describe sources and manifestations of ambiguity in the risk assessment process, and (iii) outline a procedure for approaching ambiguity in a wider context of risk-informed decision-making. The paper is delimited to engineering risk assessment for strategic decisions involving major accident risk. The paper is structured as follows: first, existing conceptions of ambiguity are reviewed in Section 2, before a new set of definitions are proposed in Section 3. Section 4 describes sources and manifestations of ambiguity in risk assessment, before a procedure for approaching ambiguity is presented in Section 5. Concluding remarks are given in Section 6.

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2. Literature on ambiguity

This section reviews common conceptions of the term *ambiguity*, both in everyday English language and in the risk literature.

2.1. Ambiguity related to a word or expression

The Merriam-Webster on-line dictionary defines ambiguity as "a word or expression that can be understood in two or more possible ways." Related to risk assessment, Colyvan (2008) similarly explains ambiguity as "uncertainty arising from the fact that a word can be used in more than one way, and in a given context, it is not clear which way is being used." This type of ambiguity is often distinguished from *vagueness*, which is something that is "stated in a way that is general and not specific" (Merriam-Webster, 2014) and hence permits *borderline cases* (Colyvan, 2008). Ambiguity is here a linguistic property of statements that can be given multiple meanings depending on the context in which they are interpreted. This conception is clear, but limited because it concerns isolated statements rather than how they appear in the risk assessment and affect the three questions of risk.

2.2. Ambiguity related to consequences

A second conception is found in the literature on risk governance (IRGC, 2005; Klinke and Renn, 2002; Aven and Renn, 2010; Renn et al., 2011), where ambiguity refers to multiple values and perspectives on the severity, tolerability, and wider meanings of risk. This is manifested in disputes about framing, ethics, and trust, and concerns social controversy in risk problems. The International Risk Governance Council (IRGC, 2005) defines two types of ambiguity:

1. *Interpretative ambiguity* refers to different interpretations of identical assessment results and "factual" states of the world (e.g., whether an outcome is adverse or not), which is a result of people processing risk information according to their own risk constructs and images.
2. *Normative ambiguity* refers to different perspectives regarding the tolerability of the risk, which comes from differences in applying normative rules for evaluating the states of the world (e.g., fairness and distribution of risk and benefits).

Both are restricted to consequences that have an impact on something humans value (Renn, 2008) and therefore address only the third question in the definition of risk. Stirling (2007) argues that "under conditions of ambiguity, it is not the probabilities but the possible outcomes themselves that are problematic," and that ambiguity concerns "contradictory certainties" that cannot be objectively described in a single risk picture. This implies that situations of ambiguity can be distinguished from situations where risk can indeed be objectively and uniquely described, which is questionable in light of fundamental risk research that does not consider risk as an ontological property that can be objectively and unequivocally assessed (Apostolakis, 2004; Aven, 2012).

A second limitation is that interpretative and normative ambiguity are vaguely defined and intimately interrelated; one can be a source of the other and it is difficult to draw the line where one stops and the other begins. Both can permeate the entire risk assessment process, and confining them to risk evaluation fails to explain how ambiguity enters risk assessment in the first place. What is more, tolerability of risk essentially concerns the tradeoff between risk and other objectives (Fischhoff et al., 1981), which may have nothing to do with ambiguity.

2.3. Ambiguity related to probabilities

A third conception is found within decision theory, statistics, and economics. This is a group of definitions that attribute ambiguity to the assessment of probabilities or uncertain events. Ambiguity is, for example, related to information quality, weight of evidence, or source credibility in the assessment (Camerer and Weber, 1992). A common feature is that ambiguity is defined in relation to whether the probability distribution of an exhaustive set of outcomes can be known. Such interpretations are found in some risk assessment applications (Basili, 2006; Dubois, 2010), but are emptied of meaning if probability, like risk, is a subjective construct as stated above. It is also unclear how ambiguity differs from mere *uncertainty*, as in Ellsberg's much cited definition of ambiguity (Ellsberg, 1961): "a quality depending on the amount, type, reliability, and unanimity of information, given rise to on eé2809s degree of confidence in an estimate of relative likelihoods of future events."

A less problematic group of interpretations relate ambiguity to *impreciseness* in subjective expressions of uncertainty. This may either concern the informative basis for expressing uncertainty (e.g., we do not have sufficient information to specify whether our probability is 0.1 or 0.9) and/or vagueness in the description of uncertain events that permit borderline cases (e.g., we do not know what it means that the event occurs) (Bedford and Cooke, 2001; Hatami-Marbini et al., 2013). Non-probabilistic approaches have developed to deal with such imprecision, such as fuzzy logic and possibility theory (Aven and Zio, 2011; Colyvan, 2008). Some consider imprecision and vagueness as synonymous to ambiguity (Kaplan, 1997), whereas others stress that they are distinct concepts (Colyvan, 2008). Ambiguity is in any case confined to the first and/or second question in the definition of risk.

2.4. Ambiguity related to human judgment

A fourth conception is found in the literature on individual and organizational decision-making. March (1987) describes "ambiguities of choice" that go beyond the assessment of consequences and probabilities to human judgment and information processing. March defines four types of ambiguity: Ambiguities of *preferences* (individual preferences may be vague, inconsistent, or unstable); ambiguities of *relevance* (the usefulness of information for decision-making may be unclear); ambiguities of *intelligence* (there may be several norms for what constitutes rational action); and ambiguities of *meaning* (lack of clarity regarding how one talks about the world and how meaning evolves from information). Richter and Koch (2004) describes the latter as lack of mutual understanding of words, symbols, and cultural manifestations in the process of creating and recreating meaning in safety cultures. Catrinu and Nordgård (2011) explain ambiguity as "internal uncertainty" in risk-informed decision-making that reflects imprecision in human judgments concerning preferences, values, and risk attitudes and may stem from insufficient understanding of problems, modeling assumptions, and so on. The disadvantage of attributing ambiguity to limitations in human judgment is that it makes ambiguity an inescapable constraint rather than a defining challenge to risk assessment.

3. New definition and categorization

To sum up, many of the existing definitions are limited to one or two questions in the definition of risk, and are problematic in light of fundamental risk research. Few of the interpretations are broad, yet specific enough to guide the identification and treatment of ambiguity in risk assessment. In the following, we propose a new