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How the risk science can help us establish a good safety culture

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ABSTRACT

This paper is about how we can make further sense of the safety culture concept in safety and risk management. Safety culture is here understood as shared beliefs, norms, values, practices and structures, with respect to safety, in an organization. We argue that the risk science (interpreted in its broadest sense to also include safety science) provides important reference points for what these beliefs, norms, values and practices should be. For example, the risk science highlights that complexity needs to be acknowledged and confronted by resilience-based strategies, in addition to the use of risk assessments. A safety culture which is not built on the state of the art of the risk science cannot be considered 'good'. The main aims of the paper are to draw attention to this issue and present a framework that can help organizations to develop a safety culture that builds on the risk science.

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Safety culture; risk science; risk analysis

1. Introduction

Considerable attention has been devoted to the safety culture concept in the safety science literature (Antonsen 2009a; 2009b; Choudhry, Fang, and Mohamed 2007; Cole, Stevens-Adam, and Wenner 2013; Cox and Flin 1998; Edwards, Davey, and Armstrong 2013; Filho and Waterson 2018; Grote 2008; Guldenmund 2000; Hopkins 2019; Parker, Lawrie, and Hudson 2006; Pidgeon 1998), and it is often discussed in relation to major accident enquiries (Cox and Flin 1998; Cullen 1990). Bad safety culture is commonly seen as an important determinant of the occurrences of incidents and accidents (Cox and Flin 1998; Cullen 1990; Griffon 2016; Hidden 1989; Reason 1997; Short et al. 2007; Vaughan 1996). The concept dates back to the International Atomic Energy Agency's (IAEA) initial report on the Chernobyl nuclear accident (Cox and Flin 1998; INSAG-11 1986). Many definitions have been presented, but broadly speaking all of them relate to some level of shared beliefs, norms, values and practices, with respect to safety, in an organization.

A key challenge addressed is to 'measure' the level of safety culture: Is it poor or good? Many systems have been developed for this purpose, providing categories of maturity levels and improvement potentials (see e.g. Filho and Waterson 2018; IAEA 2009; IChemE 2014; Parker, Lawrie, and Hudson 2006). If we study these systems, there are some typical characteristics of

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what is considered a good safety culture. For example, it is commonly highlighted that there should be a

> "commitment to the improvement of safety behaviors and attitudes at all organizational levels; an organizational structure and atmosphere that promotes open and clear communication where people feel free from intimidation or retribution in raising issues and are encouraged to ask questions; a propensity for resilience and flexibility to adapt effectively and safely to new situations; and a prevailing attitude of constant vigilance" (Olive, O'Connor, and Mannan 2006, 10).

For other characteristics, see e.g. INSAG-44 (1991).

There will be a continuous discussion regarding what are the best characteristics of good as opposed to poor safety culture. The present paper aims to contribute to this discussion by highlighting what are considered current risk science principles (risk science interpreted broadly to also cover safety science). Ideally, the shared beliefs, norms, values and practices in an organization should be in line with the best knowledge of the risk science. It is, however, difficult to obtain such an alignment when this knowledge is not easily accessible. If we consult the literature on risk and safety, it is not clear what fundamental principles should be applied. It can be argued that it is not meaningful to look for such principles, as there are many different perspectives and 'schools' providing input to the risk and safety fields. We reject, however, such a reasoning. Risk science is not yet broadly recognized as a distinct science today, but it is developing, and considerable work has been conducted over the years to establish a foundation for this science. By highlighting the basic ideas and principles of this science, we aim to stimulate a discussion on what are to be considered its scientific pillars and, consequently, the reference points for what a good safety culture should be built on.

The paper is organized as follows. First, in Section 2, we provide a brief review of basic safety culture theory, to clarify how we understand this concept. In Section 3, we present a framework for how to develop a safety culture which integrates risk and safety principles. A case is used to illustrate the framework. Section 4 discusses the framework and its use, and, finally, Section 5 provides some conclusions.

2. The concepts of safety culture, sociotechnical systems and epistemic community

In this section, we look more closely into some of the fundamental ideas and concepts in relation to safety culture, as a basis for the framework presented in Section 3. We review the history of safety culture and basic safety culture theory, extending the discussion of Section 1. Focus is placed on the safety culture concept, the issue of what a good safety culture means and how safety culture relates to safety principles and risk. We also discuss the concepts of sociotechnical systems and epistemic communities. These concepts are considered to provide fundamental building blocks for a risk-founded safety culture.

2.1. The safety culture concept

The safety culture concept can be traced back to the aftermath of the Chernobyl nuclear power accident and the need of the IAEA to find a concept by which to explain the top managers' decisions and employees' performance that contributed to the accident (INSAG-11, 1986; Toft 1992). The IAEA defines a safety culture as "the assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, protection and safety issues receive the attention warranted by their significance" (IAEA 2019). Since 1986, the safety culture concept has obtained broad acknowledgement in different industries and contexts (IChemE 2014; INSAG-44 1991; Short et al. 2007; The European Railway Safety Culture Declaration 2016). There has, however, been considerable discussion about both the understanding of the concept and how it is to be used in safety management (Grote 2015; Guldenmund 2010; Reiman and Rollenhagen 2014; Silbey 2009; Swartz 2000). The problems are partly linked to the fact that the concept builds on theories from many different disciplines, such as psychology, organizational psychology, anthropology and sociology. Depending on the discipline and underlying assumptions, different features are highlighted. For instance, cognitive and ideational aspects are emphasized by psychologists, whereas organization level aspects or structural aspects and practices are emphasized by sociologists and political scientists.

It is common to distinguish between two opposite understandings of culture: the anthropological and the instrumental understandings (Edwards, Davey, and Armstrong 2013; Silbey 2009). The former refers to culture as a process, formed in interactions between an organization's members, which is an emergent phenomenon that cannot be steered anyhow (Bieder and Bourrier 2013; Gherardi and Nicolini 2000; Silbey 2009).

The latter, instrumental understanding, builds on the opposite perspective: that the culture to a large extent can be steered or managed (Edwards, Davey, and Armstrong 2013; Eisenhardt 1993; Reason 1997; Schein 2004; Swartz 2000). Organizations can, for instance, structure their activities, allocate resources and affect processes in ways that are beneficial to safety. Top managers play a key role in this regard, by leading the work on developing the organization's goals, policies and strategies. In this paper, we adopt the instrumental understanding of culture but also acknowledge the relevance of the anthropological approach to culture and safety culture.

Many safety culture definitions emphasize ideational and cognitive factors, such as shared beliefs, understanding, assumptions and values (Guldenmund 2000; Reiman and Rollenhagen 2018), but do not reflect structural aspects or social factors such as power relationships (Antonsen 2009b; Hopkins 2019; Silbey 2009). In this paper, we adopt a broad definition of the safety culture concept that embraces ideational, structural and social factors. Safety culture can then be defined as shared beliefs, norms, values and practices, as well as structures (including functions and related social relationships), with respect to safety, in an organization (+expanded from Pidgeon 1991; Guldenmund 2000). We will use this definition in this paper.

In the literature, the dissension concerning the definition of the safety culture concept has been strongly emphasized (Antonsen 2009a; Edwards, Davey, and Armstrong 2013; Filho and Waterson 2018; Glendon and Stanton 2000; Guldenmund 2000; Hopkins 2006; Naevestad 2009). Yet, it is possible to identify broad agreement when it comes to the basic ideas underpinning the safety culture concept. On an overall level, many of the various definitions show strong similarity (Edwards, Davey, and Armstrong 2013; Glendon and Stanton 2000), especially with regard to ideational and cognitive aspects. The safety culture theory and practice are to a large extent founded on the more general notion of organizational culture as used throughout the social and management sciences (Cox and Flin 1998; Schein 2004). We define organizational culture as shared beliefs, values, norms, practices and structures in the organization (Guldenmund 2000; Pidgeon 1991; Schein 2004). Thus, the only difference between safety culture and organizational culture is that safety culture specifically relates to safety, whereas organizational culture covers all functions in the organization, including those that are not linked to safety.

Organizational culture starts to develop immediately when people interact with each other. Members of the organization observe how other members behave, and reciprocal expectations concerning appropriate behaviour start shaping (Berger and Luckmann 1991). These expectations then become internalized as norms by organizational members, and these norms form the grounding pillars for the organization's culture. Organizational culture has coercive power over individuals via expectations (which are felt as social pressures by individual members) and positive and negative sanctions that have effects on individuals' actions. Individuals have a tendency to avoid negative sanctions (punishments) and to act according to norms. Newcomers in the organization are taught the formal and informal norms and rules. As culture in general, organizational culture is seen as a relatively long-lasting phenomenon, which changes slowly. Culture is reproduced but sometimes also challenged in everyday action by the organization's members.

Organizational culture either enables or constrains safe performance, for instance by allowing open discussion of safety concerns or by suppressing it (Bienefeld and Grote 2012; Detert and Edmondson 2011;).

2.1.1. Core elements of the safety culture concepts and their interrelationships

We divide the safety culture concept into three core elements, in line with the above definition: i) the mindset and understanding (including values, norms and beliefs), ii) structures (including how organizations are split into units and what functions these units have) and iii) practices. These three features are interrelated. Mindset and understanding are often seen as guiding practices, and, in this sense, it can be argued that there is an underlying assumption regarding the causal connection between mindset and practices. However, people cannot always act according to their values. There are many intervening factors, such as everyday pressures, social expectations and hierarchies, which constrain actions. Yet, a causal type of connection between mindset and practices is commonly assumed to exist in the safety culture literature. Reversely, practices influence the mindset, as practices provide new knowledge, and in this sense affect the understanding. Similarly, organizational structures can be seen as a manifestation of understanding and practices. It is through practices that organizational structures are maintained, challenged and even changed. Yet, structures are relatively stable and thus difficult to change. Structures enable or constrain practices and mindset. In general, these connections between structures, practices and mindset are important in understanding the dynamics of the safety culture concept.

2.1.2. What is a good safety culture?

Having defined safety culture, the question arises: What is a good safety culture? The question is based on normative and instrumental understandings of safety culture that mean, as mentioned above, that the organization is able to structure its activities, allocate its resources and affect its processes in ways that are beneficial to safety. Since safety culture comprises shared beliefs, norms, values, practices and structures (including functions and related social relationships), with respect to safety, in an organization, an immediate answer is provided: The shared beliefs, norms, values, practices and structures are 'good' with respect to safety. As briefly discussed in Section 1, this 'goodness' is often defined by referring to the commitment to and alignment with some defined safety principles. A number of schemes have been developed for classifying such principles (Filho and Waterson 2018; Grote 2018; Möller et al. 2018; Parker, Lawrie, and Hudson 2006).

An example is provided by IAEA (2009), which points to the following five principles: 1) safety is a clearly recognized value, 2) leadership for safety is clear, 3) accountability for safety is clear, 4) safety is integrated into all activities, and 5) safety is learning-driven (IAEA 2009, Safety Guide GS-G-3.1). Each of these five principles is divided into attributes. For instance, the principle "safety is a clearly recognized value" refers to attributes such as the high priority given to safety is shown in documentation, communications and decision-making; safety is a primary consideration in the allocation of resources; the strategic business importance of safety is reflected in the business plan; and individuals are convinced that safety and production go hand in hand. Furthermore, "leadership for safety is clear" points to among others the following attributes: senior management is clearly committed to safety, commitment to safety is clear at all management levels and there is visible leadership showing the involvement of management in safety-related activities. These attributes provide a basis for assessing the strength and weaknesses of organizations' safety culture.

Another example is the so-called DISC (Design for Integrated Safety Culture) model (Reiman and Oedewald 2007). This model consists of two layers. The outer layer includes the organization's main functions (such as safety management and change management), and the inner layer embraces six criteria for ensuring a good safety culture. These six are the following: 1. Safety is a genuine value in an organization. 2. Safety is understood as a complex and systemic phenomenon. 3. Hazard and core task requirements are thoroughly understood. 4. Organization is mindful in its practices. 5. Responsibility is taken for the safe functioning of the entire system, and 6. Activities are organized in a manageable way. As the IAEA's safety culture framework, the DISC model refers to more specific attributes, which can help in the assessment of the strength of the safety culture.

2.1.3. Safety culture and safety principles

Möller et al. (2018) present a broad structure for classifying safety principles. The authors distinguish between three categories: i) those that aim to identify safety problems (e.g. experience feedback), ii) those that increase capacities and resources to cope with problems, and iii) those that prioritize which problems to tackle. Examples of the second category are the safety culture and the defence-in-depth principle, whereas cost-benefit analyses and the so-called 'graded approach' constitute examples of principles related to the third category.

The 'graded approach' is a relatively recent example of safety principles used to prioritize which problems to tackle (IAEA 2014). For instance, in the nuclear context, regulators can use this approach in planning inspections, to inform what should be inspected, how the target should be inspected, as well as how often and to what extent. In Finnish requirements for licensees, it is stated that the management system shall be developed and applied with consideration of the safety significance of the operation (YVL A.33 2019). The assessment of safety significance shall take into account, for example, the following: complexity of the organization's operations; complexity, uniqueness and novelty of product or function and the resulting lack of experience; and risks related to the plant operation, based on, for example, probabilistic risk assessment (PRA).

Safety culture as a safety principle can be seen as a proactive tool, thus providing capacity to cope with problems (Möller et al. 2018). Safety culture has often been seen as complementary to the defence-in-depth principle (INSAG-11 1986; Toft 1992). The latter provides technical safety barriers, whereas safety culture provides human and organizational safety barriers. However, today, the defence-in-depth principle is also used in the organizational context, as "Institutional strength-in-depth (INSAG-2727 2017). The institutional strength-in-depth concept refers to core nuclear safety actors and their interrelationships, as well as internal barriers that keep organizations vigilant in terms of safety. Inter-organizational aspects are a new dimension that is brought into the safety culture context. These aspects create challenges when it comes to creating a common, strong safety culture across organizations.

Analogously we can relate resilience management (engineering) and a good safety culture. Resilience management contributes to safety, by its focus on responding, monitoring, learning and anticipating, and adopting a systemic approach reflecting technical, human and organizational factors, meeting both known and unknown types of hazards and threats (Hollnagel et al. 2011). Continuous learning and systemic approaches to safety have been incorporated in many safety culture frameworks and models (Reiman and Oedewald 2007; IAEA 2009, Safety Guide GS-G-3.1).

Measuring the 'goodness' of the safety culture is challenging, as discussed for example by Filho and Waterson (2018) and Antonsen (2009a). A key question is to what degree a good safety culture corresponds to a higher safety level and reduced accidents. The basic idea of the safety culture concept is that there is such a link; sharing the good beliefs, norms, values and practices should result in good performance. Unfortunately, it is difficult to prove such links through empirical research. The issue has been thoroughly discussed in the literature (e.g. Antonsen 2009a; Dekker, Cilliers, and Hofmeyr 2011; Filho and Waterson 2018; Flin 2007; Hopkins 2006; 2012; Short et al. 2007).

2.1.4. Safety culture and risk

The relationship between safety culture and the risk field is reciprocal, as it is between, for example, management and the risk field. The safety culture enables and constrains the organization's activities as regards risk understanding and risk management. Similarly, if adopted by the organization, new risk science developments can fertilize the safety culture, leading, for example, to better awareness of risks.

The safety culture theories and models do not relate explicitly to risk and risk analysis. They may refer to risk by stating that people need to be aware of hazards and risks related to their work, and indirectly these theories and models could address risk principles. For instance, the IAEA safety culture definition, "the assembly of characteristics and attitudes in organizations and individuals, which establishes safety as an overriding priority, protection and that safety issues receive the attention warranted by their significance", calls for risk assessments to determine what is "warranted by their significance", i.e. to determine what arrangements and measures should be given priority. In this sense, risk analysis can be seen as guiding the safety culture work, but risk considerations are not much addressed in the safety culture literature. The shared beliefs, norms, values and practices have been connected to commitment to and alignment with safety principles, thus only indirectly addressing risk, as safety and risk are closely linked.

There is not much literature discussing safety culture and risk. An interesting contribution is made by Grote (2015). She provides examples from the NASA organization, where engineers were not able to deal with qualitative risks, because their training and competence were restricted to quantified risks. The organizational culture was characterized by a strong emphasis on quantification. Little space was left for discussing qualitative aspects of risks. The example illustrates that the 'goodness' of the safety culture is closely related to the fundamentals of the risk field and science: here, how to assess and characterize risk. We will also refer to Wahlström and Rollenhagen (2014) and Reiman and Rollenhagen (2014). These authors point to the fact that technical issues and risk assessments are not often addressed in the safety culture literature. The focus is on human and organizational aspects. However, for safety culture to be 'good', all aspects of relevance need to be considered, as the goal is 'good' shared beliefs, norms, values, practices and structures, and these relate to hard as well as soft issues.

2.2. The concepts of sociotechnical systems and epistemic communities

The concept of sociotechnical systems dates back to the UK Tavistock Institute of Human Relations and studies on the implications of human factors for the work system (Emery and Trist 1960; Trist and Bamforth 1951). The sociotechnical systems view and its development has to a large extent been stimulated by complexity theories (Davis et al. 2014; Harvey and Stanton 2014). The sociotechnical concept refers to complex interdependences between various systems, both technological and organizational, as well as interconnections between levels of phenomena (often referred to as the micro-, meso- and macro levels). Rapid technological changes, e.g. in the IT sector, accelerate the ageing of technology, and an increased level of automation of work machines creates new vulnerabilities, for example as a result of failures or disturbances of wireless signals (Dadhich, Bodin, and Andersson 2016). These challenges require organizational measures, to be prepared for the external changes – which also have internal effects – and to be able to deal with the issues that affect safety. There are many types of external factors that affect the organization in a complex sociotechnical environment, some of which make it difficult to obtain a common understanding of risk and safety across the organization. Two examples are the increasing internationalization of industries and the increasing layers of supply chains, which are characterized by many stakeholders and parties.

Sociotechnical systems are characterized by continuous processes of change and the emergence of different interconnections between systems. The result is uncertainties and a potential for surprises (Turner and Pidgeon 1997; Kleiner et al. 2015; Leveson 2012). The sociotechnical system perspective requires organizations, their management systems and safety culture to highlight the human and organizational aspects in relation to technology, for the different types and levels of phenomena. The perspective challenges the conventional safety culture focus on single organizations and what is occurring inside the organization—safety-critical organizations also need to assess and take into account external risks and their effects on the organization (Ylönen et al. 2017). If the organization is not able to do this, it will experience unsuccessful system performance and accidents in the long run (Hollnagel et al. 2011; Leveson 2012).

The epistemic community concept refers to networks of professionals and experts with shared knowledge claims (Campbell and Carayannis 2013; Meyer 2015), for example about the 'truths' concerning issues linked to risk and safety. The epistemic communities provide a rationale for the risk and safety related actions, including, for instance, on methods and approaches to be used for assessing and managing risks and safety. The epistemic communities also embrace internally defined criteria for weighing and validating risk and safety related knowledge.

A closely related concept to epistemic community is 'community of practice', which refers to common practices associated with a set of problems to which their professional competence is directed (Haas 2001), for example how to conduct risk assessments in the organization. While the sociotechnical systems highlight the organization's external factors and their potential effects on safety, the concept of epistemic community emphasizes the criticality of the organization's internal thinking and shared assumptions related to risks and safety.

Learning is an important aspect of safety culture (IAEA 2009). The community of practice and epistemic community concepts provide some additional ideas regarding learning, for instance that the communities produce a shared repertoire of routines, sensibilities, 'truths', artifacts, tools, stories and styles (Lave and Wenger 1991, 98; Wenger 2000), which affect learning. These factors may prevent people from learning new things that contradict the organization's existing beliefs and routines.

3. Risk science and safety culture

The aim of this section is to develop ideas and knowledge on how to use and make sense of risk science principles in safety culture. First, in Section 3.1, we provide a short review of basic risk science theory and its link to safety science, with a special focus on the link between risk principles and safety principles. Then, in Section 3.2, we present a framework for how to develop a safety culture that integrates risk and safety principles. Finally, Section 3.3 looks into a case to illustrate the framework.

3.1. Risk science and its link to safety science

Safety is commonly understood as absence from undesirable events, accidents and losses (e.g. Leveson 1995; 2004). However, looking into the future, these events and effects are unknown, subject to uncertainty. Thus, the safety concept relates to both the consequences of the activity considered and related uncertainties, in other words what is commonly referred to today as risk; see for example the Society for Risk Analysis glossary (SRA 2015a) and Aven, Renn, and Rosa (2011). Adopting such an understanding of risk, safety is the antonym of the risk concept. A high level of risk corresponds to a low safety level and vice versa. The link between risk and safety has been thoroughly discussed in the literature; see for example Möller, Hansson, and Peterson (2006) and Aven (2009). As discussed in these references, the safety concept can be viewed as the antonym of risk only in the case of a broad risk interpretation as outlined above. Using a narrower risk perspective based on probabilities, the antonymity cannot be justified.

However, equally commonly, the safety concept is considered the same as 'safe' and associated with low and acceptable risk (see e.g. Aven 2009; Ayyub 2003; Harms-Ringdahl 2001;

Lowrance 1976; SRA 2015a). When it is stated, for example, that safety is achieved, this type of understanding is adopted.

The present paper is based on a 'broad' understanding of risk, as referred to above and used for example in SRA (2015a). Following this perspective, a distinction is made between an overall conceptual definition of risk and how risk is measured or described. Probability-based metrics constitute an important category of such measurements. The perspective includes many others as special cases.

Using this set-up, safety principles can also be considered as risk principles. Safety science can be viewed as a sub-science of risk science (Aven 2020; Grote 2018). In practice, however, there has been a separation between these sciences, with rather isolated developments of principles and methods, as illustrated for example by the scope and focus of the two scientific journals, *Safety Science* and *Risk Analysis*. The present paper seeks to enrich the safety literature, and the instrumental safety culture approach in particular, by highlighting relevant risk theory and risk principles that are not commonly recognized or absorbed by the safety community. The purpose of the paper is not to perform an 'all-inclusive' review of such theory and principles but to point to the issue and provide some illustrating examples. In Section 2, we mentioned a case discussed by Grote (2015). Following, for example, the recent guidance document by the Society for Risk Analysis (SRA 2015a; 2017b), see also Aven (2018), risk is in general not adequately described by numbers, using a quantitative approach. Hence, a safety culture founded on quantitative methods alone would have to be characterized as poor. Qualitative judgements are needed, as the probabilities are founded on some knowledge, and this knowledge could be more or less strong and even wrong. This fact leads to judgements of the strength of the knowledge, as well as processes to identify potential surprises relative to this knowledge.

As for safety principles, there are many types of risk principles, developed by different researchers, 'schools', societies, etc. Here, we will focus on the SRA (2015a,b, 2017a,b) documents, which have been developed by a group of senior risk scientists with a considerable variety in background and competencies, and the ISO 31000 standard on risk management, which strongly influences the risk field and profession.

The SRA (2017b) document provides a set of principles, defining what is understood as high-quality risk analysis, covering risk understanding, risk assessments, risk communication, risk management and governance. When it comes to basic terminology, it builds on the SRA (2015a) glossary. Concerning the above discussion about risk characterizations, the SRA (2017b) guidance document states, for example, the following principle:

> Quantitative measures of uncertainty (typically, probability and imprecise probabilities) should be supplemented with characterizations of the knowledge that these measures are based on. Such characterisations may cover lists of assumptions and judgments of the strength of the knowledge. (SRA 2017b)

Two other examples of principles, concerning risk management, are:

> Three major strategies are needed for managing or governing risk: (I) risk-informed strategies, (II) cautionary/precautionary/robustness/resilience strategies (meeting uncertainties and potential surprises), and (III) discursive strategies. In most cases, the appropriate strategy would be a mixture of these three types of strategies. The higher stakes involved and larger uncertainties, the more weight on the second category and the more of interpretative ambiguity and normative ambiguity (different views related to the relevant values) the more weight on category III.
>
> This process of balancing different concerns can be supported by cost-benefit methods, but this type of formal analyses needs to be supplemented with broader judgements of risk and uncertainties, as well as stakeholder involvement processes. (SRA 2017b)

Acknowledging these principles as 'good' risk science, it is not difficult to think about a related poor safety culture. For example, we can think about a case where there is a shared belief in the organization that traditional cost-benefit analysis—with its weight on expected values—provides the proper instrument for making judgements about the suitability of risk reducing measures. Another case could be that there is a shared understanding in the organization that, if only resilience were sufficiently highlighted, the overall risk would be properly managed. Risk science highlights that complexity needs to be acknowledged and confronted by resilience-based strategies, but different instruments are needed for adequately managing risk. Measuring the benefit of investing in resilience is difficult as resilience is a strategy that is to meet also non-planned types of events. Such an investment can contribute to avoiding the occurrence of a major accident, although the effect on calculated probability and risk numbers could be relatively small. A culture for building resilience is therefore critical for the proper risk handling.

The importance of the safety culture can be illustrated also through the use of the ALARP (As Low as Reasonably Practicable) principle. This principle states that measures that can improve safety should be implemented unless one is able to show that the costs are grossly disproportionate to the benefits gained (Ale, Hartford, and Slater 2015, Aven 2020). The challenge with the principle and this approach is that it presumes the existence of an underlying driving force for producing measures with ALARP in mind. Without such measures, risk reduction will not be obtained. Thus if the culture is not supporting this type of generation of risk reduction measures, the principle will not work as intended. The ALARP principle recognizes the need for balancing development and protection, but it can be argued that protection is the primary consideration the ALARP principle seeks to support - and measures that promote protection and safety should normally be implemented - only in the event that one is able to document a gross disproportion, the measure need not be implemented. Hence as mentioned above, if there is a shared belief in the organization that traditional cost-benefit analysis provides the proper instrument for verifying ALARP the focus of the criterion is in reality shifted away from protection to measures that promote development and growth. Similar comments apply for the ALARA principle (As Low as Reasonably Achievable).

Finally in this section, some comments concerning the ISO 31000 standard (ISO 2018). This standard refers to many fundamental principles of risk management, for example the importance of leadership by top management. The standard is, however, a market-driven, member-consensus based document, which does not represent or reflect risk science. It has not been approved by the scientific risk science community. To illustrate this point, consider the way risk is defined and understood in the standard: risk is "the effect of uncertainties on objectives" (ISO 2018). If a safety culture is developed which is based on this shared norm, we will argue that it is a poor culture, as the definition lacks scientific rigour, is unclear and restricts the risk concept to objectives, which is unfortunate. We refer to the detailed discussion and justification of these claims in Aven and Ylönen (2019).

The above discussion demonstrates that there will always be a debate on what is the current state of the art of the risk science, as for all sciences. Standards provide guidance for practical applications, but they should be used with care, as they are not science-based. There could also be disagreement between scientists, and normally that is the case, and it is considered a prerequisite for a living science. Nonetheless, there is need for the scientific community to develop guidance documents, approved by the community or significant parts of it, to be used in practice. The SRA documents are viewed as such documents and are consequently referred to in the present paper.

3.2. Building a safety culture on safety and risk science

This section presents a framework to help organizations develop a safety culture that builds on risk and safety science. The main features of the framework are shown in Figure 1. On the left side of the figure is the safety culture, with its three interrelated elements, as defined in Section 2: i) the mindset and understanding (including values, norms and beliefs), ii) structures (including functions) and iii) practices. On the right side of the figure are some 'key contributors', such as the risk and safety sciences.

The middle column of the figure illustrates some concrete ways for obtaining a good safety culture, using these key contributors. These are examples derived from insights from the safety

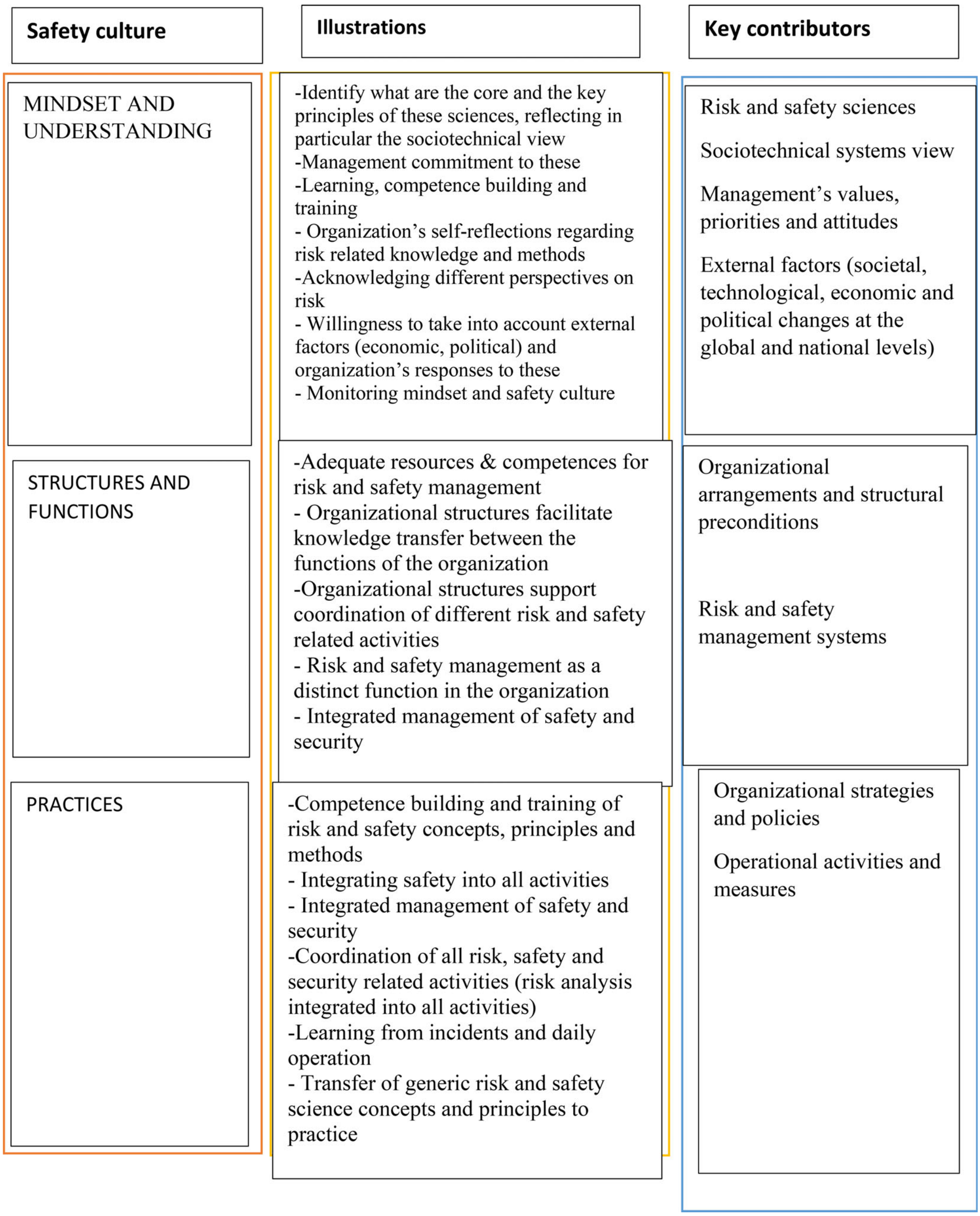

Figure 1. A framework for developing a good safety culture.

and risk sciences, and studies on organizations. The framework will be explained and discussed in more detail in the following subsections.

3.2.1. Mindset and understanding

As shown in Figure 1, the framework points to the following key contributors to the mindset and understanding:

- Risk and safety sciences
- Sociotechnical systems view, including organizational and technical factors
- Management's values, priorities and attitudes
- External factors (societal, technological, economic and political changes at the global and national levels)

'Mindset and understanding' refer to shared values, beliefs and norms in an organization. These ideational factors are critical for guiding safe performance in the organization, for example as regards how to understand and assess the risk and safety. If the mindset and understanding are that risk is adequately captured by probabilistic risk analysis, there would be a culture problem in the organization according to the framework, as risk science explains that risk in general is more than probabilities; refer to the discussion in Section 3.1. The culture is not in line with current risk science. The sociotechnical systems view can be seen as an element of the risk and safety sciences but is here explicitly highlighted, as it is considered an essential part of modern risk and safety science knowledge. 'Sociotechnical' refers to the increasing interconnectedness of organizational and technical factors and the need to consider these simultaneously, because interconnections create complexities, which may create unanticipated events (Aven and Ylönen 2018; Harvey and Stanton 2014); refer to the discussion in Section 2.2.

For organizations to use the risk and safety sciences as a reference for the safety culture, two specific tasks are identified in Figure 1: "Identify what are the core of these sciences and the key principles, reflecting in particular the sociotechnical view", and "Management commitment to these". For the former task, we refer to Section 3.1. There will always be a discussion regarding what is the core of a science, and considerable work is needed to establish the concepts and principles to be used. Documents from risk and safety societies like SRA, as well as from standardization organizations, provide guidance for this purpose, but, as discussed by Aven and Ylönen (2019) and in Section 3.1, care has to be shown when using standards as references as these are consensus-driven rather than science-based. For the latter, it is basic knowledge that the implementation of and adherence to these concepts and principles would not be successful unless the management of the organization were to fully support the task. The managers have the power to intervene if the safety level or the safety culture indicators go in the wrong direction. It is their duty to implement measures to monitor and follow up the development of the safety culture (Swartz 2000). Managers can intervene via strategies and policies, and initiate training programmes, if, for example, the mindset and understanding are not in line with current risk and safety science knowledge. For approaches and methods for monitoring the safety culture level, see Sections 2. Ways of enhancing these approaches and methods incorporating aspects from the risk science and Figure 1 should be considered.

Competence building and training are a key instrument, as most people lack basic knowledge of the risk and safety sciences, and we know that the understanding of the core concepts and principles of these sciences is challenging. Learning is a relevant part of competence building regarding risk and safety, and therefore also the way learning is understood is critical; refer to Section 2.2. It is possible to differentiate between different types of learning, such as individual and organizational learning (Argyris 1982). At the organizational level, learning is constrained by a shared repertoire of beliefs, norms and routines (Wenger 2000), which may hamper learning new things. Therefore, learning new things would also require 'unlearning' old ones. Thus, learning as a phenomenon is closely related to the mindset, practices and structures of an organization.

Closely related to this discussion are the management's values, priorities and attitudes, which are highly relevant for the weight given to different measures and activities, such as training, and the strength of the management commitment to the principles of the risk and safety sciences. The degree of self-reflection is also relevant here. Self-reflection captures the idea that the organization's experts should reflect upon their risk knowledge for specific activities and how they analyse and manage the risks. Improvements require such reflections. An essential aspect in this regard is that the 'truths' of the experts and the organization are identified, in line with the epistemic community concept.

Equally important is the awareness of external factors, such as political, economic and technological changes. These external factors may have direct or indirect effects on the organization, as described in Section 2.2. For example, changes in economic factors can lead to cost reductions, influencing the volume and depth of training in the organization. Awareness and follow-up of such changes and related risks are thus critical for maintaining the right mindset, in line with current risk and safety science knowledge.

A safety culture means shared understanding about risks and safety but also appreciation of allowing a variety of perspectives. Only with such variety would it be possible to obtain the necessary awareness of all the different aspects relevant to risks and safety, and to ensure a questioning attitude, able to see the signals and warnings pointing to possible incidents. A questioning attitude towards assessment results, methods and assumptions is fundamental for identifying problems and improving the safety culture.

3.2.2. Structures and functions of an organization

As shown in Figure 1, organizational arrangements, structural preconditions and the risk and safety management systems are an essential part of the organization's safety culture. By 'structures', we refer to an institutionalized framework, within which the interactions in the organization occur. Structures include economic resources, norms, roles and responsibilities, and division of labour in the organization.

The structural preconditions relate, for example, to adequate economic resources available for risk and safety related activities. Structural preconditions embrace competence requirements and competence building as regards risk experts. 'Structural preconditions' also refer to how the organization is structured as regards its different departments, units and functions, such as strategic management, change management, competence management, as well as the issue of whether a distinct risk and safety management unit is established. The established units and functions point to the issues that are considered important in the organization.

The way the organization is structured in departments and units and the way the roles and responsibilities are defined in the organization affect the safety culture, the collaboration and the flow of information between these different functions and units and related experts. Relevant interfaces between roles and responsibilities need to be identified, because they affect the risk and safety related activities.

For many types of organizations, to ensure that risk and safety aspects are given the attention they require in the organization, it can be argued that a separate risk and safety unit would be needed that can monitor the risk and safety performance and provide necessary guidance to the management and others. However, such a unit also represents a challenge, as it is the management and leaders that have the responsibility for safety, not the risk and safety experts. Care has therefore to be shown, so that the proper balance is obtained for such a unit between being a support function and, at the same time, being able to be a driver for improved safety.

Risk and safety science of today, with its foundational link to the sociotechnical systems view, highlights a holistic perspective on the state and condition of the organization. Successful performance and avoidance of accidents require that the organization's structures and functions support this perspective. Knowledge management constitutes an essential instrument in this regard. The organizational structures influence the knowledge transfer from the risk field to various organizational units and the specific cases and applications. It is then essential that the organizational structures allow for and stimulate the adequate coordination of different risk related information and knowledge, in line with current risk science principles.

In high-risk industries, corporate safety and process safety are often dealt with by different units and experts. Since corporate related aspects, such as economic pressures and risks, may affect safety related decisions and investments, corporate safety and process safety related aspects should be considered together. As mentioned earlier, the organizational structures should contribute to the coordination of the different types of risks and the related flow of information and knowledge. For instance, the organization's structures should support integrated management of safety and security, as there are strong dependencies between these two types of risk; see for example Chen, Reniers, and Khakzad (2019) and Reniers and Khakzad (2017). Both security and safety can be dealt with within a risk framework (Amundrud, Aven, and Flage 2017).

3.2.3. Practice

As seen from Figure 1, practices are considered an organic part of and manifestations of the organization's safety culture. Practices include organizational strategies, policies, operational activities and measures. Furthermore, as discussed in Section 2.1, there are close interrelationships between the mindset, structures and practice aspects of safety culture. As mentioned in Section 3.2.3, competence requirements and competence building, as regards risk experts, constitute basic elements of the organization's structural preconditions for good safety culture, thus having close connections to mindset and practices.

Several concrete measures that can contribute to the development of good practices are highlighted in Figure 1, including integration of safety into all activities in the organization, ensuring that all functions in the organization consider risk and safety related aspects. In addition, integration of safety and security related knowledge is relevant, as there is a strong dependency between these two types of risk, as mentioned in the previous section. Furthermore, coordination of all risk related activities is crucial, so that a variety of risk related knowledge can be effectively used to support the organization's decision-making.

Learning from daily operations, and particularly incidents, is a key measure in this regard. However, care has to be shown; the platform for this learning—in relation to how the organization identifies and investigates the relevant events—needs to be sufficiently broad to allow for key beliefs and assumptions to be challenged (Maslen and Hayes 2016; Ylönen 2019). The learning itself needs broad risk and safety thinking, in line with current risk and safety science, that takes both technical and organizational aspects into account.

Successful practice means that the generic risk science has been efficiently translated into the real-life situations—a transformation from abstract knowledge to concrete knowledge. Experience shows that this is challenging, and extensive training is essential.

3.3. An illustrating example

This section presents an example of an organization using the framework depicted in the previous section. The example is fictitious and somewhat extreme but is still considered realistic, based on the authors' experience from industry, such as the nuclear industry. The experience basis includes, for example, interviews with a number of members of organizations belonging to this industry.

The organization studied is characterized by a safety culture where the 'risk world' is strongly associated with PRAs, with risk described by probabilities and expected values. All documents related to risk build on PRAs, and discussions in meetings and studies of risk make reference to the concepts, principles, methods and models of the PRAs. Managers at all levels adhere to this understanding and practice.

Now, suppose the organization is subject to a safety review, and questions are raised about the safety culture. Are the shared beliefs, norms, values, practices and structures as sound as they should be? A decision is made to apply the above framework. The following discussion points to some observations and findings for the three key safety culture elements shown in Figure 1: mindset and understanding, structures and functions, and practices. Through this simple example, we seek to illustrate what the framework can add to safety and, in particular, to the safety culture.

3.3.1. Mindset and understanding

The first main activity is to identify what are the core and the key principles of the risk and safety sciences, reflecting in particular the sociotechnical view. This activity may, for example, lead to the conclusion that the current PRA-focus on risk and the related understanding of risk are too narrow: important aspects of uncertainties and knowledge are not captured; refer to Section 3.1. The issue also strongly affects the way risk is handled, as the acknowledgment of surprises and the unforeseen, particularly in complex systems, requires that due weight is given to robustness and resilience. It turned out that attempts had earlier been made by some of the risk experts in the organization to broaden the perspective on risk, but the efforts did not lead to changes, as management resisted them. The official argument used was that the current thinking and practice were rooted in the appropriate regulations and standards of the industry. Another reason may have been that the broader risk perspectives considered could be more demanding to relate to, from a management point of view, with stronger weight on the knowledge dimension and in particular the potential for surprises.

An extensive programme for competence building and training was initiated, for all levels of the organization, starting with the top managers in the organization. A change in the mindset and understanding of risk would not happen overnight, but a process was started which was expected to lead to a fundamental new mindset and understanding of risk in the organization. Several instruments were introduced, to monitor the changes in the culture on this point, including interviews and surveys.

3.3.2. Structures and functions

In the organization, a strong organizational separation between different areas working with safety, security and risk had existed. The framework points to the need to facilitate knowledge transfer between the various functions of the organization, for example between safety and security. Although there are considerable differences in the way safety is managed, compared to security, it is important to ensure some level of integration between these functions, as they relate to each other. Contemporary risk science shows how risk concepts, principles and framing provide the overriding structure and logic for how to understand, assess, communicate and manage both safety and security.

The organization considers establishing a unit for the better integration of safety and security management. In addition, considerable resources are used to strengthen the knowledge management, both hardware and software, as well as to define roles and responsibilities regarding the knowledge management, i.e. to identify, capture, evaluate, retrieve and share all of the organization's information assets, such as databases and documents, which are relevant for the integrated management of safety and security risks.

3.3.3. Practices

Considerable efforts were made to translate the risk science knowledge into practice. Training was highlighted, which incorporated the novel features on mindset and understanding referred to above, with integration of both safety and security risks. Considerable efforts were also made to use insights gained from various incidents, to update not only probabilities but also the knowledge supporting these, as discussed in Section 3.1.

Furthermore, from the sociotechnical viewpoint, incident investigations reflecting both organizational and technical aspects were carried out, using experts from both areas. In this way, versatile insights into incidents were obtained, supporting the learning processes. In addition, efforts were made to integrate key safety and security management functions, without violating some fundamental differences concerning, for example, transparency-related requirements, which are different for safety and security.

4. Discussion

The proposed framework is designed to help organizations develop a safety culture that builds on risk and safety science. Key criteria for judging the safety culture to be good or mature are that the risks are understood, assessed, communicated and managed according to the best knowledge available, i.e. relevant concepts, principles, approaches and methods are state-of-the-art. In particular, this means that the organization’s external factors (economic, technological) are given due attention, in line with the sociotechnical perspective on safety. Macrolevel external factors, such as global or national economic depressions, have direct or indirect effects on organizations. Economic depression may constrain the organization’s activities, leading to a need to cut investments and costs and to organizational changes. Another example of an external factor is technological changes that create pressures for organizations to change their technologies. In this way, external factors could have safety significance and need to be reflected by the safety culture.

The safety culture would be poor if it were reactive, with too much focus on what has happened—incidents and accidents—and not addressing what can happen: the future and the risks. It would also be poor if too much focus were on quantitative analysis, not acknowledging the importance of qualitative aspects, such as, for example, the knowledge strength supporting risk characterizations and numbers. A safety culture which relies too much on quantitative risk assessments, as in the case presented in Section 3.3, or on risk assessments in general, would undervalue the importance of thinking robustness and resilience, which enables surprises and the unforeseen to be dealt with.

The framework presented in Section 3 seeks to highlight such issues. In relation to safety culture, it is common to address safety science principles as discussed in Sections 2 and 3 but not the fundamentals of risk science so much. The framework is to be considered a conceptual set-up, which focuses on some core elements of importance for the safety culture. Further developments and refinements of the framework are foreseen, when more extensive testing and use of the framework have been conducted. Real-life studies applying the framework are necessary, to assess it strengths and weaknesses and to improve and give further substance to the current high-level structure.

The example studied in Section 3.3 is simple and somewhat caricatured but illustrates the point that a safety culture, which is based on shared beliefs, norms, practices and structures that are not updated on what is prudent risk understanding, analysis and management, is a poor culture and improvements are needed. There will always be discussions on what is the current risk and science knowledge, but, if the ambition for the safety culture is not to reflect the state of the art, there is a reason to question the overall organizational culture and goals. Continuous improvements and top performance do not then seem to be emphasized enough.

5. Conclusions

The main contribution of the present paper is considered the knowledge generated by integrating the safety culture concept and contemporary risk science, and particularly the framework presented in Section 3, to help organizations develop a safety culture that builds on the fundamentals of the risk science. This science (interpreted in its broadest sense to also include safety science) provides essential reference points for what the shared beliefs, norms, values and practices forming the safety culture should be. There is a continuous discussion on what constitutes the state of the art of any science, so also for risk science. The current paper points to the recent developments and recommendations made by the Society for Risk Analysis, which provide a framework for interpreting relevant concepts and a summary of fundamental principles for what is good or prudent risk understanding, assessment, communication and management. To develop a good safety culture, alignment of these principles should be sought. The framework in Section 3 provides support for how to obtain this. Further testing and analysis of the framework is needed to prepare it for real-life use, as discussed in Section 4.

The framework is not meant to be a complete description of risk and safety science based safety culture. It is, however, considered an important contribution to that direction. What could be developed further in the framework is better understanding of the mechanisms between the three components of safety culture, namely, mindset, structures and practices, as well as better understanding of the social relationships, including power relationships in an organization that have effects on the formation of shared norms, values and beliefs related to risks and how risk and safety related instruments are implemented in an organization.

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