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Principles of adaptive management in complex safety–critical organizations

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ABSTRACT

This paper contributes to safety management by bringing in ideas from organizational complexity theories. Much of the studies and the literature on organizations as complex adaptive systems have focused on how to produce new innovations or how to increase financial effectiveness. We take the view that safety–critical organizations can be perceived as complex adaptive systems, and we discuss what this means for the management of safety. Our aim is to elaborate on the issue of what kinds of principles the management of safety should be based on in complex adaptive systems. In brief, we suggest that safety management should be *adaptive*, building on several different principles. Based on literature on complex adaptive systems we first identify the general features of complex adaptive systems, such as self-organizing and non-linearity, which need to be considered in management. Based on the features of complex adaptive systems, we define eight key principles of adaptive safety management and illustrate usefulness of the principles in making sense of the practice of safety management.

1. Introduction

The way safety is managed in an organization depends heavily on the beliefs and assumptions the management and personnel have concerning organizational behaviour and safety. Both researchers and practitioners within the safety field have tended to focus on an absence of negative events as being a proof of safety. Variance in human activity has been seen as a major causal factor in accidents and incidents. Safety management has thus focused on identifying the possible ways things can go wrong, and then seeking to prevent such possible deviations by implementing barriers, emphasizing procedural adherence, creating redundant systems, supervising work and making clear the distribution of responsibilities. The numbers of accidents and other negative events, such as breakdowns, adverse events and process leaks, have been used as indicators of safety. This classical safety management paradigm views organizations as machine-like entities. However, disappointments in the results achieved by the classical safety management paradigm together with the evolution in several scientific disciplines have led to an emerging view of safety as something more than the negation of risk. This new paradigm for safety management is supported by an increased application of complexity theories in safety science (e.g. Dekker et al., 2011; Goh et al., 2010; Dekker, 2011a).

We view safety as a dynamic and emerging property of the organization, including both the social and technological aspects of it. Safety management is here defined as the practice of managing the production of safety in an organization. This paper contributes to the safety management literature by bringing in ideas from organizational complexity theories. We take the view that safety–critical organizations can be perceived as complex adaptive systems and we discuss what this means for the management of safety in such systems. Our aim is to elaborate on the issue of what kinds of principles the management of safety should be based on in complex adaptive systems. In brief, we suggest that safety management should be *adaptive*, building on several different principles and changing to fit the environment and situational factors of the organization (cf. Obolensky, 2010).

2. Research strategy and methods

This paper is mostly a theoretical study, building on the literature on complex adaptive systems and safety management. However, the origins of the present study are found in two lines of empirical research carried out in parallel by the authors. The first

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line of research has focused on safety management in the nuclear power industry (Reiman et al., 2011; Reiman and Rollenhagen 2012a, 2012b). The second line of research has been carried out in the health care domain (Pietikäinen et al., 2012). Our empirical research and our experiences in various safety consultancy projects in different safety critical fields led us to the realization that many managers and experts in safety–critical domains experienced contradicting demands, but lacked a theoretical framework to conceptualize what management principles they needed for trade-offs and balancing. We noticed that the contradictions perceived by the managers and experts had similarities to the Competing Values Framework (CVF, Cameron and Quinn, 2011; Quinn and Rohrbaugh, 1983). However, we felt that by analysing the conceptualizations of managers and experts we could only get as far as we did, that is point out the lack of frameworks and the fact that these contradictions had similarities to the CVF. But the findings could not be explained solely by that framework. Consequently, we needed to develop a more elaborated and complex framework for making sense of safety management in practice. The analysis of the case material also suggested that safety management (perhaps not surprisingly) was a very complex task, and that models of safety management should not simplify the task too much. We therefore decided to approach the challenge from the opposite viewpoint: given that safety management is about managing a complex adaptive system, and given what we know about the characteristics of such systems, what principles for safety management can we then extract from this knowledge? Here we had to turn to the literature concerning complex adaptive systems and safety management, and approach safety management from a more theoretical perspective. Nevertheless, we acknowledge that our reading of that literature has been guided by our previous empirical findings.

Based on our empirical findings and the literature, we developed a framework of adaptive safety management that we describe in this paper. The paper is structured as follows. We begin by introducing key concepts of complexity and the complex adaptive system. Then we consider the challenges of managing these systems first in general and second in safety–critical domains. In Section 4 we introduce our conceptualization of the principles for management of safety in complex adaptive systems and illustrate usefulness of the principles in making sense of safety management. Section 5 summarizes our main arguments and outlines some expected critique.

3. Complex adaptive organizations – a selected oversight of the literature

The literature of complexity is massive. In this paper, we mainly and selectively draw on the applications of complexity theories in organization and management research based on the assumption that they are most relevant for understanding the management of safety–critical organizations.

3.1. Complexity science and the properties of complex adaptive systems

'Complexity' can be defined as a feature of a system that arises as a result of the interactions of the individual components of the system (Dekker et al., 2011, p. 941; McDaniel and Driebe, 2001, p. 12). This means that the behaviour of the system cannot be reduced to an aggregate of the behaviour of its constituent components (Dekker et al., 2011, p. 941). 'Complexity' has to be differentiated from 'complicated' (Cilliers, 1998). Complicated systems, at least in principle, can be taken apart and put together again (e.g. a jet airliner). A complicated system is thus reducible to its constituent components, whereas a complex system is not.[1] 'Complexity science' is the study of complex systems. McKelvey identifies two schools of complexity science: the European and the American school (McKelvey, 2004, pp. 318–321). While the European school draws mostly on the natural (physical) sciences, the American school draws on life sciences, social sciences and chaos theory. However, complexity science should not be perceived as a single unified theory, nor as two complementary theories, but rather as a loose collection of theories and models of adaptive, complex systems. Complexity science perceives organizations as 'complex adaptive systems'.

A 'complex adaptive system' (CAS) is a collection of individual *agents* with freedom to act in ways that are not always predictable, and whose actions are interconnected so that one agent's actions change the context for other agents (Plsek and Greenhalgh, 2001). These agents interact in a non-linear way creating system-wide patterns (Eoyang and Holladay, 2013) and higher and higher levels of complexity (McMillan, 2008, p. 60). The agents differ from each other and none understands the system in its entirety. This diversity is a source of invention and improvisation. As the agents are interdependent on each other, relationships among agents can be considered to be the essence of a complex adaptive system. Understanding a complex adaptive system requires understanding of patterns of relationships among agents (McDaniel and Driebe, 2001, p. 15).

Based on literature on complex adaptive systems (Stacey, 1996; Cilliers, 1998, 2010; Holland, 2002; McDaniel and Driebe, 2001; Plsek and Greenhalgh, 2001; Kurtz and Snowden, 2003; Sterman, 2006; Plowman and Duchon, 2007; McMillan, 2008; Goldstein et al., 2010; Eoyang and Holladay, 2013), we have in Table 1 summarized the following general features of organizations as complex adaptive systems[2].

Self-organization and emergence represent two key concepts for understanding the dynamics of complex adaptive organizations. The phenomenon of self-organization entails that control in complex adaptive systems is always distributed rather than centralized. Thus, distributed control strategies are needed in order to manage complex organizations. The related (but also philosophically controversial, see e.g. Corning (2002), Sawyer (2005), Johnson (2006), and Bedau and Humphreys (2007)) concept of emergence denotes the arising of global characteristics of the system (in an organizational context these characteristics refer, for instance, to practices, structures and processes) from characteristics of agents and their relationships, without being reducible to these characteristics[3].

[1] Complexity science treats systems as genuinely complex. This ontological stance differs from an epistemological view of complexity. In the epistemological view, things can look very complex but closer inspection may reveal that complexity is a consequence of our limited knowledge of the system rather than a property of the system itself (ontology).

[2] In complexity science, the term 'strange attractor' is important. Attractor in general refers to properties toward which a system tends to evolve. An attractor is a 'strange attractor' if the exact values of the system in the attractor cannot be predicted. In organizations, 'strange attractors' can be things such as shared practices, values and standards of performance that define the space inside which individual performance takes place (see Knowles, 2002, p. 98). However, the features listed in Table 1 cover the issues we have deemed relevant for the purpose of this study, and the omission of strange attractor is intentional. In this paper, we refer directly to the organizational factors of importance to emergence and self-organization.

[3] A typical example given of an emergent property is the way in which consciousness emerges from the interactions between neurons in the brain (Cilliers, 2010, p. 4; McMillan, 2008, p. 63). McMillan (2008, p. 63) equates the collective identity of groups to a similar emergent phenomenon. The emergent phenomena are variously called either patterns (Stacey, 2005; Eoyang and Holladay, 2013), or system properties (McDaniel and Driebe, 2001). The views of the effects of the emergent properties on individual agents (in a process called downward causation) are the most contested part of the debate on emergent properties (see Sawyer, 2005). Some authors distinguish weak emergence from a strong emergence, suggesting that only strongly emergent properties such as norms or values have causal powers toward individuals (Sawyer, 2005). On the organizational level, strongly emergent phenomena can include shared beliefs and practices (culture) as well as work climate (Sawyer, 2005).

Table 1
Key features of complex adaptive organizations.

Feature	Description
Non-linearity	Inputs are not necessarily proportional to outputs. Small changes in local conditions can have major effects on the overall system. Systems are (composed of) highly responsive and interconnected feedback loops that can reinforce or attenuate inputs. Moreover, all effects have several parallel contributing factors, instead of one or few causal chains as in linear systems. There are 'spiralling, iterative cycles of cause and effect' (Eoyang and Holladay, 2013, p. 63) instead of one root cause for each effect. On the other hand, complex adaptive systems also exhibit time delays between 'causes' and 'effects', which can lead to overshoots in interventions
Emergence	Emergence is a result of the pattern of connections among diverse agents. As a consequence of these interactions, new patterns of relationships, new system level properties and structures emerge. Emergent properties forming from the interaction of the agents cannot be traced back to those individual agents. Yet these patterns have an effect on the agents. The irreducible nature of emergent properties means that the properties of the whole are distinctly different from the properties of the parts. Examples of emergent properties include consciousness in a brain, norms or climate in a work group
Self-organization	*Self-organization* denotes the emergence of new structures, patterns and new forms of behaviour in the system as a consequence of agent interaction and connections (Prigogine and Stengers, 1984). Organizations are continually self-organizing through the processes of emergence and feedback. Thus, the phenomenon of self-organization is the collective (emergent and ever non-permanent) result of local yet non-linear interactions among agents. Complex adaptive systems (CAS) can thus self-organize into even greater states of complexity. Yet, self-organizing creates order in the system: in a CAS, order is a result of the properties of the system itself rather than an intentional achievement of an external controller
Far-from-equilibrium conditions	'Complex living systems ... seek to exist in a balance between order and disorder, regularity and irregularity, stability and instability, equilibrium and non-equilibrium' (McMillan, 2008, p. 54). This is sometimes called the edge of chaos, the condition of high requisite variety and creativity. It is also the edge of order or the edge of stability. Being far from equilibrium also means that the system is in a continuous process of flux and change. Change in these systems is a natural tendency, not something initiated by an outside force. This capability also allows these systems to self-organize and adapt to changes in their environment
Coevolution	A complex adaptive system exists within its environment, but it is also part of that environment. Environmental changes require a change in the system. However, since the system is part of its environment, change in a system changes its environment, creating a process of mutual change and evolution. Further, the environment including the organization can be considered a CAS of its own, which also learns and adapts (see nested systems)
Nested systems	Complex adaptive systems are sometimes called 'systems within systems'. For example, organizations are composed of individuals who themselves are complex adaptive systems (and their brains can each be considered to be a CAS). These nested systems increase the diversity and uncertainty inherent in the 'parent system'
History-dependence	A CAS cannot be rewind back to its earlier form and state. Actions are thus irreversible, and the past helps to shape present behaviour. Agents learn from their previous experiences and change their actions accordingly. History dependence also means that solutions can seldom be copied from one system to another: what works in one organization cannot be replicated in another organization, since they each have their own distinct histories (McMillan, 2008, p. 112). It has also been pointed out that, in general, a CAS is highly sensitive to its initial conditions (the butterfly effect). However, Cilliers (1998) reminds us that such chaotic behaviour results from the non-linear interaction of a relatively small number of equations. In complex organizations, however, there are always a huge number of interacting components making the sensitivity to initial conditions of lesser importance than general history dependence

The view of an organization as a complex adaptive system is fundamentally different from the traditional view of organizations as 'rational systems whose structure, rules, and authority are intended to create stability, and in which any major adaptation is directed from the top of the organization' (Plowman and Duchon, 2007, p. 111). The behaviour of complex adaptive systems is impossible to predict in detail, and the actors in those systems are always acting under uncertainty (cf. Norros, 2004). Complex adaptive systems possess an inherent capacity to become more adaptable, by generating novelty through natural departures from what is expected. These unexpected events can be called fluctuations, or experiments in novelty (Goldstein et al., 2010, p. 103). Given an ontological assumption of complexity as something real, it is fallacious to think that one day we will be able to reveal the whole complexity in all its details and be able to predict the complete functioning of the system by means of thorough methods. The unpredictability of complex adaptive systems is thus fundamental, and emergence will always create surprises and novelty (McDaniel, 2007, p. 24; McDaniel et al., 2003, p. 271; Goldstein et al., 2010, p. 78).

3.2. Management of complex adaptive systems

Complexity science-based models of management emphasize the importance of building on emergence, especially when striving for innovations or organizational development and change (Goldstein et al., 2010). However, we argue that, since self-organizing and emergence are inherent features of complex adaptive systems, they need to be taken into account even and especially in such a setting where safety is one of the salient values of the organization. Building management on emergence and self-organization requires that the managers 'let go of the reins of control' (McMillan, 2008, p. 172; Blomme, 2012) and trust the employees to create novelty within the constraints of the organizational purpose and overall goals. However, a strong sense of purpose is needed for a system to self-organize in an effective manner (McMillan, 2008, p. 175; Ford, 2010). McMillan (2008, p. 198; see also Ford, 2010) argues that successful complex adaptive organizations are 'able to self-organize without any centralized control because they have a shared core purpose and simple underlying principles that guide them in their everyday actions'.

Traditional hierarchical views of leadership are regarded as less useful in complex adaptive systems. Managing complex adaptive systems is often said to require adaptive leadership, which can be seen as a complex dynamic process that emerges in the interactive 'spaces between' people and ideas (Lichtenstein et al., 2006). In a complexity science-based view, 'leader' and 'leadership' refer primarily to the process of leading (Goldstein et al., 2010; DeRue, 2011), or to a complex interplay of many interacting forces of a social system (Uhl-Bien et al., 2007, p. 314) rather than to individual people. Plowman and Duchon (2007, p. 118) summarize that 'leadership is about designing systems for emergence'. However, this does not imply a passive role for leaders. Leaders have an active role in creating emergence in complex systems. Emergence is a key requisite for the adaptability of organizations. Moreover, this adaptability can only emerge 'if there are constraints or boundaries that consistently operate on the choices and actions of the individuals in the system' (Goldstein et al., 2010, p. 14).

Approaches based on complexity theory emphasize the importance of interaction and relationships. Goldstein et al. (2010, p. 31) argue that 'continuous effort is needed to strengthen, widen, and deepen the capacity of the relationships, so as to transport resources and knowledge more quickly and effectively'. They use the term 'interaction resonance' to denote the deepening of the information exchanged through interaction. They conclude that successful management in an adaptive organization means 'setting up conditions for positive interaction and interdependence' (Goldstein et al., 2010, p. 42).

Sometimes complex adaptive systems are described as being 'on the edge of chaos', or aiming to be at the edge of chaos (McMillan, 2008, p. 204). The edge of chaos implies that these systems are not chaotic, but neither are they totally stable. Balancing stable and chaotic aspects, and dipping into each of them when necessary, is the hallmark of a well-adapting system (McMillan, 2008, p. 204). Change and stability is a basic and well established tension in organizations. Eoyang and Holladay (2013, p. 19) propose that 'well-informed trial and error' is the only viable strategy in finding an optimal solution to all the relevant interdependent pairs, such as change versus stability. Being well-informed means 'understanding the pairs that are essential to success, understanding how they relate to each other, and having the knowledge and skills required to make the wise moves' (Eoyang and Holladay, 2013, p. 20).

Quinn and Rohrbaugh's (1983) study suggests that 'organizational researchers share an implicit theoretical framework, and, consequently, that the criteria of organizational effectiveness can be sorted according to three axes or value dimensions' (p. 369). The first dimension is related to organizational focus '...from an internal, micro emphasis on the wellbeing and development of people in the organization to an external, macro emphasis on the well-being and development of the organization itself' (p. 369). The second dimension is related to organizational structure, with, at the one end, emphasis on stability and, at the other end, emphasis on flexibility. The third dimension is related to means-end relationships—e.g. planning and goal setting vs. outcomes (productivity). Cameron and Quinn (2011; see also Cameron et al., 2006) developed these findings into the Competing Values Framework (CVF). This framework, although it does not fall explicitly under the complexity science 'tradition' (see, however, Tsoukas, 2005, p. 236), shares many features with complex adaptive systems literature, such as the emphasis on paradox and tensions (see also Quinn, 1988; Weick et al., 1999, p. 53; Raisch et al., 2009; Farjoun, 2010; Obolensky, 2010; Eoyang and Holladay, 2013). CVF emphasizes that successful managers need to work simultaneously with several contradictory logics and shift their dominant value sets when circumstances so require (Quinn, 1988). This type of adaptive management also acknowledges the role of such 'traditional' management strategies as centralization and control, which tend to be de-emphasized by complexity science-based management theories, making the CVF an important building block for a model of adaptive safety management. Thus, embracing complexity theory should not mean discarding all previous management theory (Obolensky, 2010). Instead of rejecting old management theories, we should better understand the limitations of these theories and complement them with other approaches (Cameron and Quinn, 2011).

Based on the above, we can already identify some key components of adaptive safety management. First, complexity science implies that there are several contradictory logics in organizations and management needs to be adaptive in balancing between those depending on what the circumstances require. Second, management has to focus on creating preconditions and organizational potential for safety instead of merely controlling and commanding employees. These preconditions include a clear purpose, simple decision making principles and positive interaction between the members of the organization. Third, the inherent uncertainty of complex adaptive systems means that there is always a need for adaptive action based on the situational constraints and possibilities. Fourth, the 'fluctuations' of the system can be used in developing the system, and thus variance in complex systems can be a source of innovation. Fifth, management is always distributed in nature. This means that leaders are also part of the system they are managing, i.e. they are agents comprising the complex adaptive system. They have to acknowledge that other human agents in the systems also influence, i.e. lead, the system.

3.3. Complexity in safety–critical organizations

Given the brief overview of complex adaptive system above, we must now try to answer some basic questions about complexity and safety: Can most safety–critical large organizations be considered as being complex adaptive systems? Can we accept the idea that surprises are inevitable in such systems as nuclear power plants or hospitals? Much of the literature on organizations as complex adaptive systems has focused on how to produce innovations or increase financial effectiveness, but how do such management principles apply to managing safety? There is growing evidence in safety research that, whether we want it or not, uncertainty, complexity and contradictory requirements are inherent in safety–critical organizations (Weick et al., 1999a; Le Coze, 2005; Grote, 2009; Woods et al., 2010; Dekker, 2011a; Amalberti, 2013; cf. Brehmer, 1991). For example, research has identified several risk-inducing characteristics of safety–critical organizations that are in line with the findings from the CAS literature. Four of these phenomena are considered below: normalization of deviance, organizational drift, information flow, and system accidents.

Normalization of deviance refers to a process where small deviations from the normal course of events gradually become the norm (Vaughan, 1996). Normalization of deviance produces a disregard for and misinterpretation – i.e. neutralisation – of potential danger signals. A signal of potential danger is information that deviates from expectations, contradicting the existing worldview (Vaughan, 1996, p. 243). This means that normalized signals are not reported, since they are no longer considered to be danger signals but signify the normal state of affairs. Aspects of organization contributing to the normalization (Vaughan, 1996, see also Dekker, 2011a) are for example: scarcity of resources (leading to the necessity of optimizing), real or perceived production pressures (leading to conflicting goals and trade-offs), uncertain and unruly technology (creating glitches such as false alarms), structural secrecy (where danger signals remain local and not subjected to any credible outside scrutiny), intolerance of dissenting opinions (which may challenge the new norms or raise safety concerns), distant information patterns (e.g. specialization of knowledge so that few people can judge the information generated by others, and formalization of knowledge sharing so that information instead of knowledge becomes shared).

Organizational drift is closely associated with normalization of deviance, and in complexity science terms is another type of an emergent pattern. When normalization deals with normative changes in the valuation of danger signals, drift refers to local modification and adaptation of centrally designed practices (Snook, 2000; Dekker, 2011a; see also Rasmussen, 1997). Snook (2000, p. 194) writes: 'Practical drift is the slow steady uncoupling of practice from written procedure ... After extended periods of time, locally practical actions within subgroups gradually drift away from originally established procedures ... Constant demands for local efficiency dictate the path of the drift.' The main reasons for the danger of locally optimizing working practices are, firstly, the loose couplings prevalent in parts of complex sociotechnical systems making it possible to change one part of the social system without immediate effect on the others, and secondly, the tendency of complex systems in some conditions to become tightly coupled[4]. When different locally adapted practices meet – when

[4] A system is tightly coupled when the parts of the system are highly interdependent, that is, when the system has time-dependent processes which cannot wait, rigidly ordered processes, only one correct way to achieve success and little slack (Perrow, 1984).

they become tightly coupled – the encounter may lead to unexpected consequences (cf. Dekker, 2011b, p. 125). Thus, since drift takes place locally, it poses a challenge for the overall management of the organization: different departments and units in the organization may work with different premises from each other. Normally, the working practices of these various organizational units are loosely coupled, meaning that a small change in one unit's practices does not *immediately* affect the other units.

Problems in *information flow* and communication have very often been identified as being contributing factors in various accidents (Pidgeon and O'Leary, 2000). It has also been shown that organizational secrecy and 'hiding of information' is built into the very structure of complex organizations (Vaughan, 1996, p. 250). The division of labour between subunits, the hierarchy and the geographical dispersion segregate knowledge about tasks and goals. Physical as well as social distance interferes with the efforts to know the behaviour of others. According to Vaughan, specialized knowledge further inhibits knowing: 'People in one department or division lack the expertise to understand the work in another or, for that matter, the work of other specialists in their own unit' (Vaughan, 1996, p. 250). Organizations take various measures to increase the flow of information, often making the process of information sharing more formal and impersonal. These formal organizational efforts to communicate can lead either to information not being read due to an overwhelming amount of it or to loss of details and impoverishing of information due to predefined categories used in electronic reporting systems and other communication forms (Vaughan, 1996). The flow of information does not guarantee that people make sense of it; rather the organizational processes should aim at promoting the seeking out of both positive as well as negative information at all levels in the organization. From a complexity science point of view, information in social systems is similar to energy in physical systems – a 'life blood' flowing through the organization and its environment (Goldstein et al., 2010, p. 10).

System accidents are caused by the interactive complexity of the system itself, hence the name system accidents (Dekker et al., 2011, p. 943; Leveson, 2004; Hollnagel, 2004; cf. Perrow, 1984). System accidents cannot be predicted by their constituent parts, as they are 'one emergent feature of constituent components doing their (normal) work' (Dekker et al., 2011, p. 942). System accidents result from the relationships between components, not from the workings or dysfunction of any component part (Dekker, 2011a, p. 128; Haavik, 2011). Woods, et al. (2010, p. 13) call complexity 'the enemy of safety', separating it from the 'old' enemy of safety; human error. Adaptation is a vital feature of complex safety–critical systems, but it can also be the cause of system failure. Many safety scientists have questioned simplified accident models such as Reason's Swiss Cheese model, and argued for models taking into account the interactive complexity and emergent properties of the system as reasons for accidents (Dekker et al., 2011; Dekker, 2011a; Amalberti, 2013). For example, there is some evidence that migration and drift cannot be controlled merely by reinforcing the existing rules (cf. Amalberti, 2013, p. 73; Snook, 2000), but rather by striving to increase positive variance (perceptions of current and potential hazards, endorsing different views and opinions) and offering personnel the tools with which to make sense of risks and the safety limits instead of merely prescribing how to deal with the identified risks (cf. Rasmussen, 1997).

Emergent system properties are both the source of risks as well as the source of safety (cf. Karwowski, 2012, p. 986). Normalization of deviance and drift are both driven by the need to adapt locally to various pressures and by structural issues affecting the flow of information. They are inherent features of organizational complexity, not faults that can be removed from the system. Thus, the characteristics already identified in Section 3.2 as essential for management of complex adaptive systems should be complemented with measures aiming at monitoring the system properties as well as identification of potential sources of risk in the system. Variance and fluctuations in the system can be the source of accidents, not only the source of innovation and change (cf. Section 3.2). Adaptive safety management requires balancing between principles that increase and utilize the system complexity and principles that seek to reduce and guard against it.

4. Principles of adaptive safety management

4.1. Defining the four pairs of safety management principles

In this paper we have adopted a view of safety as being an emergent property of the system. Further, we have defined organizations as complex adaptive systems. Based on these premises that have been elaborated in Section 3, we define four pairs of eight principles of adaptive safety management. These are presented in detail below.

Fig. 1 illustrates the eight principles of safety management illustrated as pairs of opposing principles (cf. Cameron and Quinn, 2011). Leaders should acknowledge that the above-mentioned principles are somewhat contradictory but still necessary for overall system functioning. This requires balancing and trade-offs between the different requirements.

4.1.1. Promote safety as a shared guiding principle

Many researchers have emphasized the need for shared direction providing goals in complex adaptive systems, e.g. Knowles (2002), Rogers et al. (2009) in the safety–critical domains, and Nonaka (1988), Lichtenstein et al. (2006) and McMillan (2008, p. 15) in non-safety–critical domains. Since agents in complex adaptive systems tend to self-organize they cannot be effectively controlled by a single top-down controller. There must be certain shared guiding principles according to which situational decisions are made. Safety has to be one of these guiding principles: a shared value in the organization. Shared vision or values acts as an orientation and catalyst for agents of the system still allowing self-organizing (Ford, 2010; Rouse, 2000). A system where everyone makes their decisions based on what is personally important to them at any given moment would not be a safe system. Promoting safety as a guiding principle requires that leaders constantly keep safety on the agenda, remind colleagues of its importance, and most importantly, show in their own behaviour and decisions that safety issues are borne in mind. Furthermore, leaders should project a shared social identity (Lichtenstein et al., 2006) and identify and give meaning to patterns in the activities and events that are happening around them (Plowman and Duchon, 2007). These patterns may indicate what the people in the system value, what they need and what is happening to them (Ibid.). Further, in order to allow people to make sense of what is going on, they need time to pay attention and interpret situations. Managers need to create time for personnel to 'create and re-enact sense and meaning' (McDaniel and Driebe, 2001, p. 25).

4.1.2. Optimize local efficiency

A certain level of efficiency is essential for the survival of any organization. Managers need to take the situational requirements into account and make judgments concerning how much effort, how much time and how much money is allocated to different issues. This connects safety management to the general management of the organization – safety cannot be managed in isolation of the core organizational processes and strategies. Furthermore, safety activities and programmes also need to be carried out efficiently, and the safety tools and methods that the workers use in

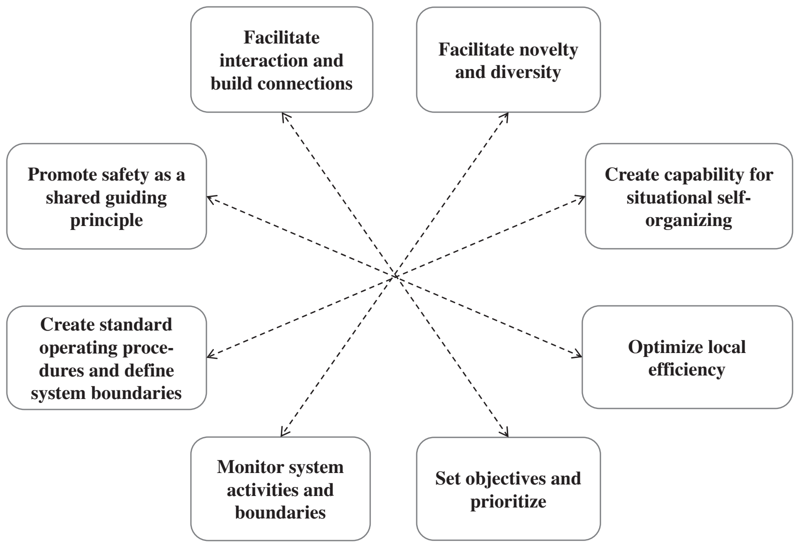

Fig. 1. The eight principles of managing safety in complex adaptive systems.

the field should not slow down the work more than necessary. Too 'heavy' safety procedures work against themselves: by making the work practically impossible to carry out as it has been designed, workers may need to take short cuts and violate the rules to accomplish their tasks. Safety managers cannot always be the force opposing production, but also the force that facilitates efficient and productive work. The resources used for safety have to be calculated and optimized just like any other function that the organization has. Safety managers need to consider 'how to achieve better and safer production, at the same cost or if possible even at a lower cost' (Amalberti, 2013, p. 62).

There are also situations where action is needed fast, and there is no time to conduct a thorough analysis of all action possibilities and plan them accordingly. Amalberti (2013, p.39) notes that the demand for 'perfect' situation awareness may even be dangerous in quickly evolving situations where the time-frame for intervention is limited. Thus, taking time and acting thoroughly and carefully is not always the safest course of action (cf. Kurtz and Snowden, 2003).

4.1.3. Facilitate interaction and build connections

Connections and interaction between agents are needed in order to guarantee organizational cohesiveness, communication and enough order for the system to both act in a structured manner and yet be flexible and self-organize when needed (Goldstein et al., 2010; McDaniel and Driebe, 2001; Weick et al., 1999b, p. 413). An environment that supports interaction is one in which people trust each other, know and respect each other's competences and are willing to share information, that is, communicate and learn from each other (McDaniel and Driebe, 2001). Furthermore, employees need to have the means, opportunities and time for communication. The importance of connections and interaction between people in complex adaptive systems has been emphasized by e.g. Nonaka (1988), McMillan (2008), McDaniel and Driebe (2001), Goldstein et al. (2010, p. 31) and Knowles (2002).

Managers are not external observers or controllers of the organization, but rather parts of the system; a manager is 'an agent of the system whose patterns of interaction with other agents is part of the overall set of factors that is leading to the dynamic behaviour of the system' (McDaniel and Driebe, 2001, p. 24). Thus, when facilitating interaction the manager needs also to pay attention to their own way of interacting and pattern of interactions: with whom does the manager usually interact, is the interaction dialogue or informing/telling, what kind of information the manager receives and what do they deliver to others, how typical are the interaction patterns and what is the possibility of chance encounters? When managers interact with the personnel, they enter into a dialectic relation where they simultaneously constrain and are constrained by others, and enable and are enabled by others (Stacey, 2005, p. 9). By creating connections between the various actors in the organization, the system also gains adaptive capacity due to the possibility of sharing task related information or helping others in their tasks.

In practice, supporting interaction means that the manager needs to go out into the field, to talk and listen to shop-floor workers as well as white collar workers, introduce people to one another and point out potential ways the various tasks and people doing them interconnect. Sometimes structures such as seating arrangements or work facilities need to be rearranged or redesigned to allow for better interaction. It can also mean discussing lessons from near-misses in other departments, or other organizations, and likewise sharing ideas and information between different units/departments. What is more, it means networking both inside one's own organization and also outside with other experts and important stakeholders. Facilitating interaction should thus reach the stakeholders of the organizations, such as the general public and other interest groups. Especially at times of crisis it is important to reach out directly to people and openly share even the difficult issues (Knowles, 2002). It helps if these connections already exist before anything negative happens.

4.1.4. Set objectives and prioritize

Leaders need to select areas where they will focus their effort and to emphasize some connections and some persons over others, depending on their potential contribution to organizational goals. A major issue here concerns the basis and the tools for setting priorities. Using risk analytical techniques (such as probabilistic safety assessments) represents one approach that can be used. However, departing from a CAS perspective, we should expect the unexpected. Consequently, priorities should also concern the development of a type of resilience in organizations that can cope with unexpected events.

Setting objectives and prioritizing requires choices about priorities – not everything can be a priority at any given time. Generally this means that not everyone's wishes can be fulfilled, but the manager needs to decide and say what is to be done – except during emergencies when adaptability and deference to expertise are needed (see Section 4.1.7, cf. Weick and Sutcliffe, 2007). This is a much more authoritative role than in the principle focusing on facilitating interaction. In this role, the manager decides what is important and what is not important for the organization, and communicates his expectations to the employees.

4.1.5. Facilitate novelty and diversity

In a complex environment the constant development of activities is an imperative. Novelty, variance and diversity are the key ingredients of development, and these need to be nurtured in the organization (McMillan, 2008, p. 110; Lichtenstein et al., 2006; Nonaka, 1988; Jordon et al., 2010). If an organization wants to learn and develop, its leaders need to 'clarify, reinforce and amplify' those daily deviations that appear to have innovation potential (Goldstein et al., 2010, p. 103). Thus, it is important to strive to create such novelty and diversity that may be beneficial to the organization's core task, not just any type of novelty. Facilitating novelty and diversity also requires a reluctance to simplify and strive to break up typical categorizations of agents (such as 'nurse' or 'pilot') or events (such as a 'design-basis-accident', a 'near-miss', or a 'level one leak') (cf. Weick and Sutcliffe, 2007; Jordon et al., 2010). This means increasing the variance in the system instead of categorizing and (supposedly) decreasing the potential sources of variance (cf. Grote, 2009). Development and change usually require a certain amount of tension in the system. Managers need to sustain this creative tension (Lichtenstein et al., 2006; Plowman and Duchon, 2007). Diversity also improves the mindfulness of the organization and its ability to improvise in novel situations (McDaniel and Driebe, 2001; cf. Schulman, 1993; Weick et al., 1999a).

Learning is a key requirement in any human system, especially so in a safety–critical system. (McDaniel and Driebe, 2001; Jordon et al., 2010; Drupsteen and Guldenmund, 2014). However, learning requires courage and admitting the need to learn more since 'to become a learner is to become vulnerable' (Berwick, 1991, quoted in McDaniel and Driebe, 2001, p. 26). Encouragement and rewarding of self-reporting of errors and near-misses is needed to give more opportunities for organizational learning (Weick et al., 1999a, p. 40). Learning is closely associated with reflecting. The manager needs to reflect and make explicit the underlying decision principles, norms and assumptions that guide the decision-making and way of working in the group. In this manner, they are open to alternative courses of action. By becoming conscious of and challenging commonly shared assumptions, the leader becomes more aware of the emergent properties, patterns of interaction, in the system (cf. Eoyang and Holladay, 2013, p. 193). Learning should also focus on the 'outliers' and 'deviations' (cf. Jordon et al., 2010, p. 229). Novelty will lead to self-organized order, potentially contributing to the system's survival. Managers can also build on deviations that are a result of self-organizing, whether the self-organizing has been task-oriented or not.

4.1.6. Monitor system activities and boundaries

Managers need to pay attention to behaviours, cultural activities and interactions that characterize the group or the organization. Managers also need to monitor for intentional violations of rules and procedures, or other unacceptable behaviour such as substance abuse or bullying. Monitoring of technology and the controlled physical processes is also critical for the system safety. Paradoxically, monitoring system activities and boundaries requires that the organization defines what can be ignored and what information is not worth analysing (cf. Weick, 1998). Monitoring always requires simplifying and only attending to those signals that are considered relevant for safety.

Auditing is one of the basic tools for monitoring safety–critical systems. Another often used method is the utilization of various safety performance indicators. Safety performance indicators can be used in gaining an understanding of the system – its past, present and potential future (cf. Hollnagel and Woods, 2006, p. 348). Typical outcome indicators such as incidents and accident counts tell mostly about the past and little about the present or future. The indicators also should help managers in guiding the system toward the envisioned future and away from other envisioned – and unwanted – futures. Organizations have to monitor and understand the reasons behind the ever-present gap between written guidelines and practice (Dekker, 2011b). The gap is a monitor indicator that implies not a violation but rather a compliance with work group norms and local expectations; "they comply with unwritten rules and operating standards that probably make good local … sense" (Dekker, 2011b, p. 128). Again, this local understanding may not capture all sources of risk.

As safety in a complex adaptive system is understood as more than the negation of risk and absence of adverse events, indicators should also focus on this positive side of safety – on the presence of something (Hollnagel, 2008, p. 75; Rollenhagen, 2010). Safety indicators should measure the presence of organizational attributes that enable safe everyday interaction – including the presence of instructions, an environment supporting interaction, the capability of the personnel to self-organize and so on. In this way, the safety indicators can be utilized proactively as part of safety management in the given organization. In this manner, they can also be utilized as part of setting objectives and prioritizing (see Section 4.1.4).

4.1.7. Creating capability for situational self-organizing

Self-organizing is both a hallmark and the key adaptive mechanism of complex adaptive systems (see e.g. McMillan, 2008, pp. 103–104; McDaniel and Driebe, 2001, p. 28) but also something that depends on the other characteristics of the system (see e.g. Eoyang and Holladay, 2013, pp. 26–30; Knowles, 2002). Leaders need to create capability for the agents in the system to self-organize in a safe manner.

Creating capability includes giving permission to cross and redefine boundaries and roles, as well as adjusting and interpreting rules and standard operating practices according to situational requirements. Self-organizing can build on resources outside the formal boundaries of the organization, or even redefine those boundaries. In order to be aware of the situational requirements, mindfulness is needed (Weick et al., 1999a). It is important that the individuals who adjust their actions carry out ad hoc decisions and interpret situational requirements, possess sufficient understanding of the possible safety impacts of their actions. A self-organizing capability builds on good understanding of the core task as well as the technology and the hazards that need to be taken care of (Reiman and Oedewald, 2007). Successful self-organizing requires adequate information, clear identity, and well-built relationships (Knowles, 2002). It builds on adaptive sensemaking that allows both honouring and rejecting the past beliefs and practices while interpreting an abundance of data into actionable knowledge (Weick et al., 1999b, p. 412, 415). Successful self-organizing often requires that the organization has generalized uncommitted resources at its disposal (Weick et al., 1999a, p. 47; Schulman, 1993).

Self-organizing also includes the daily adjustments that need to be made to match the work as imagined (by designers, planners and writers of instructors) and the actual conditions under which the work is carried out. These conditions can never be known exactly in advance, and thus there is always a need to adjust activities based on the situation at hand (Hollnagel, 2009).

Self-organizing may require revising the goals of the situation, i.e. changing what groups are trying to accomplish. The existing rules and practices may not apply in the new situation, thus requiring all activities to be decided on the spot. Karl Weick has borrowed the French term *bricolage* (tinkering), first used by anthropologist Claude Levi-Strauss to describe how the natives (employees) utilize whatever tools and resources they have at hand and recombine them into new cultural products. Safety management should aim at developing practitioners' skills in judging when and how to adapt guidelines to local circumstances (Dekker, 2011b, p. 127), how to make do with whatever resources and tools they have at hand (Weick, 1993), and how to take action even when (and especially when) circumstances are unclear (McDaniel and Driebe, 2001; Amalberti, 2013, p. 39), and how to not only adapt to the environment but also affect the environment, that is, coevolve with the environment (McDaniel and Driebe, 2001, p. 30).

The advice about being sensitive of when rules can be applied can easily be misunderstood: it is not a general advice not to follow safety rules, but to be aware of the fact that rules cannot always compensate for skills, knowledge and adaption to local circumstances. Thus, this principle resembles what La Porte and Consolini (1991) have termed the ability of the organization to reconfigure from centralized to decentralized structures in times of crisis, and what Perin (2005) calls the 'real-time logics' of control. However, we stress the fact that the reconfiguration of both structures and practices takes place all the time, and management needs to facilitate and support it.

The downside of self-organizing and making adjustments is that, when organizational practices gradually evolve, there is a risk of parts of the organization drifting into risky practices (Snook, 2000; Dekker, 2011a). In order to allow safe self-organizing, leaders as well as other agents of the system need to remain mindful of potential emerging risks (McDaniel and Driebe, 2001). Both normalization of deviance and drift (see Section 3.3) can be attributed to self-organizing. Thus, safety–critical organizations need to create the organizational capability for self-organizing (competence, situational understanding etc.), and yet strive to constrain the self-organizing within certain boundaries.

4.1.8. Define system boundaries and standardize activities

Complex adaptive systems need explicit boundaries, since there are no natural all-inclusive boundaries between the various overlapping human systems (Goldstein, 1994; Plsek and Greenhalgh, 2001; McMillan, 2008, p. 115). This is especially so since safety–critical organizations are systems that should perform according to some public expectations or other normative criteria. Standardizing activities and enforcing system boundaries can compensate for the inherent novelty of self-organizing. Planning, organizing and coordinating enables collective sense-making and a reference point for actors in the organization (Ford, 2010).

Defining boundaries and limits to the system is important even if the real boundaries of complex adaptive systems are always inherently fuzzy and the activities are impossible to describe in detail. Without any structure, the system would behave chaotically. Roles and responsibilities are a key feature enabling the coordination of activities. Defining a system boundary does not, however, imply that a defined system should be perceived as self-contained without exchange over the predefined boundaries. On the contrary, defining system boundaries too restrictively in the analysis of safety may create a false assumption regarding causal influences and predictability of events.

Safety analyses and risk assessments are part of the activity of defining the system boundaries. This 'calculated logics' of safety control, as Perin (2005) calls it, represents the design basis or boundary of acceptable performance (Rasmussen, 1997). Safety policy acts as the documented safety boundary that the organization wants to establish. In the nuclear industry, unexpected events are called 'out of design basis accidents' in comparison to the calculated (and controlled) design basis accidents.

Every organization needs standard operating procedures and standardized ways of responding to everyday ordinary challenges. Organizations need to define rules and standardize activities. They should predefine activities as standard operating procedures, and set barriers against typical human errors and violations. Organizations also need to take into account the applicable laws and legislations and devise internal rules of conduct that comply with the law. It is not sensible to rely on situational judgment and personal experience in everyday work tasks. In terms of coordination, it is also important that the expectations concerning working practices are as clear and reasonable as possible. This also requires certain shared decision making principles (see Section 4.1.1).

4.2. Embracing the safety management paradox

Management of a complex adaptive organization is inherently a contradictory activity, and it always requires balancing between various tensions, competing demands and irresolvable dichotomies (Plsek and Greenhalgh, 2001; McMillan, 2008; Eoyang and Holladay, 2013). These tensions can never be completely 'resolved'. Fig. 2 illustrates the tensions between the safety management principles. Each principle is based on a different set of values. For example, 'facilitate novelty and diversity' is based on valuing high degrees of variance in the system, whereas 'monitoring system activities and boundaries' values low system variance.

The framework illustrated in Fig. 2 suggests that there are a number of tension domains where trade-offs are being made. These domains and their associated trade-offs are described in Table 2 and expanded below.

4.2.1. The primary tensions

The first tension in Table 2, 'responding to contingencies', reflects a basic difference in the strategy for building adaptive capacity into the system, and thus also a basic difference in how the organization anticipates, responds and learns (cf. Hollnagel, 2008). The former aims at building specific organizational capacity for anticipating and responding to a tractable set of events. It aims at building repeatability and coordinated response to expected perturbations. The latter builds general adaptive capacity to the system without providing specific predictions of probable or improbable events (cf. Weick et al., 1999a, p. 61).

The second tension relates to the role of variance in the system. Variance can be both the source of failures as well as successful adaptation (cf. Hollnagel, 2004, 2009). Variance in a positive sense can mean requisite variety in the competence and skill set of personnel. Increase variance can also lead to an overemphasis on deviations, novel solutions and new ways of working without clear boundaries for what is acceptable and what is not. However, monitoring and controlling system variance treats variance basically as something to be reduced and can lead to inflexible routines or even to denial and suppression of differences (Knowles, 2002, p. 150).

Woods (2009, p. 499) argues that organizations need mechanisms to assess the risk that the organization is operating nearer to its safety boundary than it realizes. This requires successfully balancing between increasing variance by questioning existing monitoring practices and bringing in new information, new variance, and reducing variance by monitoring whether the system is behaving within pre-established parameters and making adjustments accordingly (cf. Weick et al., 1999b). The new information can widen the range and scope of the organization's risk analyses and other risk control measures. For example, Pidgeon and O'Leary's (2000, p. 22) concept of 'safety imagination' calls for a consideration of emergent or ill-defined hazards that have not

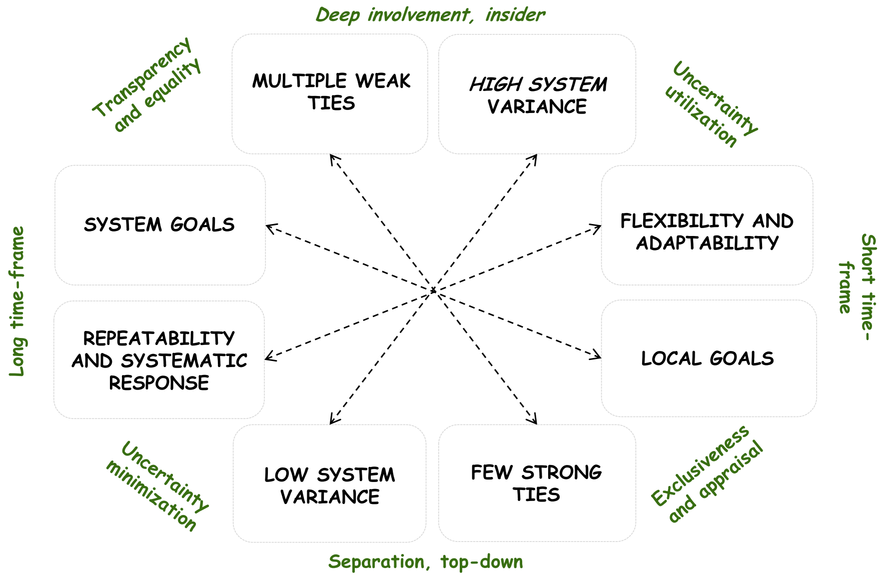

Fig. 2. The principles and their combinations create eight tensions.

Table 2
The framework illustrated in Fig. 2 suggests that trade-offs are made between eight thematic issues or dichotomies, creating four tensions and four second-order tensions.

Tension domain	Description of the necessary trade-offs
Primary tensions	
1. Responding to contingencies	This tension includes a trade-off between building capacity to anticipate and systematically and repeatedly respond to expected contingencies versus building capacity to adapt and flexibly respond to any contingency
2. Disposition toward variability in the system	This tension includes a trade-off between low system variance and high system variance. Too large a variance in the system leads to a lack of shared boundaries or practices whereas too small variance leads to inflexible routines or even to denial and suppression of differences
3. Connections/relations in the system	There is a trade-off between having multiple weak ties and between having few strong ties between organizational members
4. Goals at different system levels	Shared systems goals such as safety, profitability and sustainability have to be balanced against local, more short-term, goals
Secondary tensions	
5. The role of time	This tension includes a trade-off between long-term issues and short-term issues. Safety issues are often chronic issues in an organization that has many other acute challenges to deal with
6. The role of uncertainty	This tension includes a trade-off between uncertainty reduction and uncertainty utilization: whether to seek to minimize uncertainties by standardizing past actions into procedures and monitoring the system boundaries, or to utilize uncertainties by increasing variance (novelty and diversity)
7. The role of the manager in the system	Separation versus deep involvement refers to a tension between how a manager conceptualizes his role in the system; is he an observer and evaluator and 'external' controller or an interacting, involved actor who acknowledges the distributed nature of leadership?
8. The role of power	This tension deals with issues of transparency and equality versus exclusiveness and appraisal. Trade-offs is needed between who to involve in decision-making, how to share information, and how to empower and involve people in a situation where formal power is never equally distributed

been identified in advance. They write: 'Avoiding disaster ... involves an element of thinking both within administratively defined frames of reference (to deal with well-defined hazards that fall within an organization's prior worldview) and simultaneously stepping outside of those frames (to at least consider the possibility of emergent or ill-defined hazards that have not been identified in advance – or which perhaps fall outside of an organization's strict administrative or legal remit)' (Pidgeon and O'Leary, 2000, p. 22).

The third tension, the connections in the system, refers to a trade-off between strong and weak ties in the system. The strength of a tie depends on the amount of time, emotional intensity, trust, and the reciprocal services which characterize the tie. Weak ties are characterized by occasional contact, lesser emotional intensity and less similarity between the individuals than is typical of strong ties. Multiple weak ties in the system are good for information flow. They are also important for the development of a sense of shared identity. On the other hand, strong ties can be a source of help in critical situations by breeding local subgroup cohesion. Strong ties require more time to maintain and thus they usually exclude a number of people outside the circle. (Granovetter, 1973, 1983) Multiple weak ties can be useful in coupling the system with its environment when many people interact with others outside the organizational boundaries (cf. Knowles, 2002, p. 151).

A lot of traditional management has focused on reducing connections by getting people to focus on their own tasks, devising organization charts, lines of responsibility and accountability. Yet, in complex systems the issues and challenges are such that connections and information exchanges between many people are needed. On the other hand, many complexity scientists warn of the dangers of too many connections: 'attention must be paid to patterns of participation, not just amount or frequency of participation' (McDaniel and Driebe, 2001, p. 17). Too many connections may lead to behaviour that never settles into any recognizable pattern of self-organization, whereas too few connections may lead to 'frozen behaviour' (McDaniel and Driebe, 2001, p. 19).

The fourth tension includes the requirements for system goals versus local goals. Shared global goals of safety, profitability and sustainability have to be balanced with local goals. These local goals can be departmental goals of achieving certain subunit goals, or individual goals to do interesting work, save time or get the work done. Actions based on the local goals have to take into account the constraints and requirements created by the global goals.

4.2.2. The secondary tensions

The fifth tension in Table 2 relates to a conflict between a short time-frame and long time-frame; safety issues are often chronic issues in an organization that has many other acute challenges and short time-frame issues (Woods and Branlat, 2011). This is due to the fact that, despite safety being a shared value at a global level, there are various performance pressures at a local and individual level which easily lead to an excessive focus on efficiency and schedule (Hollnagel, 2009; Woods and Branlat, 2011). Similarly, creating connections and networking is an activity that seldom has short-term benefits. A balance has to be found between short-term needs ('to get the job done', 'to manage another day') and long-term sustainability and capacity building.

The sixth tension relates to the role of uncertainty: whether to seek to minimize uncertainties by standardizing past actions into procedures and monitoring the system boundaries or to utilize uncertainties by increasing variance and focusing on the future (see Grote, 2009)? Understanding what is really going on in a complex adaptive system is challenging. Since all the agents that act in the system have the possibility of creating their own future, knowing exactly what will happen in the organization in the future is practically impossible. In fact, instead of talking about the future, it would be more beneficial to talk about several possible futures. McMillan (2008, p. 188) considers envisioning potential futures to be an essential task for managers: 'they need to think of the future, to anticipate the many possibilities it may hold, to accept that they have no way of knowing how events will turn out and [still] be ready to respond and adapt to many eventualities.'

Standardization and rule enforcement are the traditional means of reducing uncertainty, but these have recently been challenged, especially when it comes to complex systems (cf. Dekker, 2011a). Despite the fact that rules and procedures minimize the uncertainty experienced by the actors, there is a downside to them at the system level: 'Barriers, as well as professional specialization, policies, procedures, protocols, redundant mechanisms and structures add to a system's complexity' (Dekker, 2011a, p. 127). Rules are based on a simplified view of reality and there is always a danger of not taking into account the true complexity of the real situation (Tsoukas and Dooley, 2011). Actors should use their personal knowledge and connections in addition to rules and procedures so as to read the actual situation and self-organize. The challenge is to determine which one should be relied on when there are contradictions between the predefined procedures and the actor's situational assessment.

The role of the manager in the complex adaptive system is the source of the seventh tension. This refers to how a manager conceptualizes his role in the system; is he an observer and evaluator or an involved actor? Observation, appraisal and evaluation are needed in order to make 'objective' decisions concerning the system, to decide on goals and the measures to take. On the other hand, leaders are always part of the system they are managing, and they need to capitalize on this fact by influencing the system as one of the system actors, as an insider. This requires abandoning the quest for an objective outside view and involving themselves in the interactions and dynamics of the system.

The final tension, the role of power, refers to the tension between who to involve in decision-making and how to empower and involve people in a situation where official power is never equally distributed. It balances transparency and equality with exclusiveness and appraisal. It also deals with the issue of information sharing, how much should everyone know about their organization, each other's tasks, and the current challenges that the organization faces?

The big question is, what decision criteria should be used to balance between the principles? Unfortunately, this question does not have a straightforward answer. If it had, safety management would be much easier than it is. The next section provides some guidelines concerning the factors affecting the choice of principles to emphasize.

4.3. Using the framework for steering the organization

We propose the following preliminary set of factors that have an influence on the selection of what principles should be emphasized in an organization at any given time (see also Grote, 2012; Amalberti, 2013):

- current level of safety,
- 'safety culture' maturity,
- organizational culture,
- the organizational core task and its inherent hazards,
- institutional environment.

The current level of safety has an effect on what is the optimal safety strategy and what are the main issues increasing risk (Amalberti, 2013). In a new organization or a new activity it is typical to start from standardizing, identification of risks, and monitoring of activities. As the basic requirements for taking care of the most apparent risks are in place, the focus should shift to uncertainty recognition and even to uncertainty promotion so as to guard against complacency and excess proceduralization. Paradoxically, this shift can also be considered a way to counter the natural tendency of systems to migrate and drift (see Section 3.3).

The paradox here is, of course, that the manner in which safety management is perceived and, subsequently, how the principles are carried out, affects how the safety level is perceived. Thus, it can be proposed that standardization should, even from the start, be accompanied with some emphasis on variety as well as capability creating, including increased mindfulness and awareness of risks (cf. Knowles, 2002). Naturally, promoting safety as a guiding principle is also needed to some degree regardless of the current level of safety.

'Safety culture' maturity refers to how highly personnel and general management value safety and how they consider safety in their tasks. This is typically closely connected with the level of safety, but these work on different time frames: a decrease in safety culture maturity can show in the safety level after a delay. Also, an increase in safety culture maturity may not immediately manifest itself as a higher safety level. In low safety culture maturity organizations, safety managers need to do more 'selling' and also aim to introduce positive variance into the organization in terms of an increased understanding of safety and its value. In low maturity safety cultures, the optimal starting point would thus be an increased emphasis on the two upper left principles in Fig. 1.

Organizational culture refers to the assumptions, values, norms and practices in the organization that define the organizational identity. These affect what kind of safety management is considered to be natural and fitting the culture. A very hierarchical organization may consider interactive safety management styles to be alien, whereas striving to standardize activities in a pioneer-like high-technology organization will probably encounter strong resistance. The safety management principles can be used not only to characterize organizations and their dominant values (Cameron and Quinn, 2011) but also to discuss potential blind spots in terms of safety management.

The organizational core task and its inherent hazards refers to the objective and object of the organization's activities (Reiman and Oedewald, 2007). The object of activity of, for example, a nuclear power plant, an aircraft, a chemical plant or a construction site, creates many of the inherent hazards that the organization has to deal with. The hazards associated with, for instance, producing electricity with water heated up by a nuclear reaction are very different from those of, for instance, constructing an office building or ore extraction and smelting. The core task and the hazards also put constraints and requirements on the kinds of safety management actions that are needed. This factor is also connected to the life cycle of the technology in question: the hazards and their uncertainties differ depending on whether the system uses proven technology or innovative new technology. In proven technologies, one further factor concerns the effect of ageing on the reliability of technology, a source of uncertainty in the technical system.

The institutional environment refers to the values, priorities and regulatory regimes of the society in which the organization operates. The institutional environment can in many cases be considered also to include the senior management and the shareholders. Amalberti (2013, p. 75) points out that safety specialists need to understand the particular 'trade-off mechanisms' in their industry in terms of societal risk acceptance. He offers the nuclear industry and medicine as examples of opposite approaches in terms of social tolerance of voluntary exposure to risk. In the nuclear industry, as well as in civil aviation, the trade-offs tend to be made in favour of safety initiatives at a centralized level. In the case of medicine, fishing as well as transportation (we could add mining, construction, and many other domains to this list), senior management tends to give priority to exposure to risk and the safety activities are mostly carried out at the local level (Amalberti, 2013, p. 75).

5. Discussion

Safety management of complex adaptive systems presents a great challenge. Classical safety management has been found to have limitations in responding to this challenge. This does not, however, entail that the old practices, principles and ideas are all necessarily out-dated. Rather we advocate a need to view these classical conceptualisations in a new light. We still need the classical tools and concepts developed over many years of experience, but we also need to complement the old principles with new principles. As complex adaptive systems comprise several semi-autonomous agents that all take part in the activity of managing safety, it is not enough only to rely on traditional, centralized control strategies. The framework illustrated in this paper aims to move safety management beyond those strategies of centralized control and propose other strategies and their relations.

There is a flavour of idealism in classical safety management – an idealism that does not seem to match with what is actually going on in organizations. People adapt continuously to new challenges, and this goes on regardless of many well-meant attempts to reduce human variability. Complementary safety management principles should focus on how we can make full use of what empirically has been found to characterize everyday work in complex adaptive organizations, rather than trying to hide behind too idealistic a façade based on taken-for-granted assumptions. Continuous adaptation usually means trade-offs and compromises between values even if safety is officially said to be a priority.

Applying a complexity science-based view of safety has other potential advantages as well. First, the idea of non-linearity inherent in complex systems can offer a way to come to a conclusion on the long on-going debate concerning what matters more in safety management and accident causation, the organization or the individual? Complexity science proposes that both matter, since even single agents in the system can achieve major consequences, both positive and negative. Also, although complex systems exhibit stochastic (irregular) behaviour, their behaviour is not random and it can (and should) be affected both from top-down and bottom-up. Complexity science offers a way out of dichotomous human or organization thinking into understanding the interaction of human and organization. Accident investigations may benefit from looking at the trade-offs made between the various management principles instead of finding latent and active failures in the organization. Also, the safety management principles can be used as a background for developing auditing and training tools for safety professionals. These auditing and training tools would be based on those ideas inherent in complexity thinking and also those underlying the principles proposed in this paper: safety is an emergent property of the complex adaptive organization and as such it cannot be standardized or controlled. Rather, organizations need to create the potential within the organization (and also outside the organization's official boundaries) for situational adaptation, reflective use of procedures, utilization of the system's collective competence and steering of the system toward increased safety potential.

Finally, it should be remembered that safety management is always iterative in nature. Adaptive management means exactly this, that one is able to choose the principle that works and change it as situations, patterns, external influences, change. The framework proposed in this paper can help managers in making sense of their current principles and suggest other potential courses of action.

Criticism of the ideas in this paper is to be expected. An argument can be made that many of the proposed 'new' safety management principles are nothing new under the sun, but something that has been with us for a long time (see for example Weick, 1979; Quinn and Rohrbaugh, 1983; Perrow, 1984). In some respect, this criticism is valid. We do not claim to have come up with eight totally new principles. However, as we have pointed out, many managers are well aware of the fact that what goes on in reality is not the same as the prescribed logic. A difference, however, between some of the new principles, is that the eight principles presented in this paper are based on a more realistic view of organizational behaviour in comparison with some of the classical ideas, and these 'new perspectives' are made explicit rather than being hidden in managers' personal experiences of effective safety management – the contradictions and ambiguities experienced in daily management practices are in this paper elevated from a 'necessary evil' to 'necessary and exploitable'. Also, the contradictory management practices are taken as based on valid scientific theories, not as something the management does while waiting for better prescriptions from safety scientists; or so some scientists like to believe. Furthermore, the present study has attempted to put the principles into a coherent framework and to provide some advice on how to balance between the principles. Much has still to be achieved in order to translate new principles into practical tools of safety management. If the principles do not translate into practical tools, these new ideas also risk being nothing more than another idealistic frame of reference for safety management.

Criticism can also be targeted at the choice of our focus on the organizational level. Many of today's challenges are global, and companies and regulators interlink with other actors in societal webs of influence. The possibilities for one company to change its practices can be questioned. Still, we do have legal entities labelled as companies that need to carry out their daily tasks as if they were semi-autonomous actors. Moreover, complexity science posits that it is possible, even if not very probable, for even a small company (or an individual) to change matters on a global scale. Similar principles can probably be found on a societal level, and further studies may look at the link between societal (including regulatory) priorities in terms of the eight principles and how these 'environmental' factors shape the companies' safety management space.

Another criticism will probably target the reductionist flavour in our paper (cf. Wynne, 2005), which may seem paradoxical when our topic is complexity. However, although we acknowledge the impossibility of control and prediction of complex adaptive systems, we also acknowledge the practical need to manage these systems as well and as safely as possible. Turning organizational complexity into eight manageable principles may be considered to be reductionist, but it can also be seen as an attempt to balance the inherent unpredictability of organizational reality and the practical need to work and live with these systems. Complexity science reminds us that we can never expect to match the complexity of the system that we wish to manage by means of our mental models of the system. But by letting go of our illusion of control and attempts at exact prediction, we can try to make do with a few simple rules that 'help with a flexible balance between the collective systems and the single actor because they support the choice of the individual while serving the shared purpose of the whole' (Eoyang and Holladay, 2013, p. 97).

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