BUILDING AN "ADAPTIVE SAFETY CULTURE" IN A NUCLEAR CONSTRUCTION PROJECT – INSIGHTS TO SAFETY PRACTITIONERS

Kaupo Viitanen [1] and Teemu Reiman [2]

[1] VTT Technical Research Centre of Finland LTD, P.O. Box 1000, FI-02044 VTT, Finland

[1] kaupo.viitanen@vtt.fi

[2] Consultant

Abstract

Nuclear power plant construction projects are challenging for safety management due to many of their inherent characteristics, which include high levels of organizational turbulence, changes in lifecycle phases, unanticipated events, interactions between multiple parties and the challenges of multicultural environment. This means that traditional approaches to improving safety might not be sufficient. To address this issue, we will view safety management from the perspective of Resilience Engineering and complexity thinking and propose a novel perspective to the practical development of safety culture in dynamic environments. We describe a revised model of adaptive safety management and use four well-known safety culture improvement methods as illustrative examples of how they can be utilized in building an adaptive safety culture.

1   INTRODUCTION

Managing safety in turbulent environments creates extra challenges for the creation of a strong safety culture. For example, in nuclear power plant (NPP) construction projects, some of the common challenges include growth of personnel at the participating companies, changes in the phase of the project as the project proceeds, various unanticipated occurrences, multiple interacting parties and multicultural environment. This implies that traditional approaches to safety assurance which have been developed for more stable organizations might not be sufficient anymore.

A novel approach to organizational management is the application of complexity theories. This approach postulates, for example, phenomena such as change through self-organization, emergent patterns that cannot be traced back to individual elements, non-linear relation between inputs and outputs and irreversibility (Reiman, Rollenhagen, Pietikäinen, & Heikkilä, 2015), and emphasizes the importance of understanding and managing trade-offs or tensions. The latter has been widely recognized in the field of organizational studies (e.g. Cameron & Quinn, 2006) and safety science (e.g. Amalberti, 2013; Woods & Branlat, 2011). We propose that an NPP construction project can be viewed as a complex sociotechnical system, involving a variety of tensions and paradoxes that can manifest themselves, for example, as conflicting organizational requirements or goals. Overall, this suggests that safety management should be based on the key features of how complex systems function, and make use of those features, not only seek to dampen them (Carrillo, 2011; Reiman et al., 2015).

Basing on the characteristics of complex adaptive organizations and existing models, Reiman et al. (2015) have proposed an *adaptive model of safety management* which identifies four tensions, each consisting of a conflicting pair of management goals: 1) *system goals – local goals* 2) *repeatability and systematic response - flexibility and adaptability,* 3) *low system variance – high system variance*, and 4) *few strong ties – multiple weak ties*. The model was used by Reiman (2015) to highlight the different roles that safety practitioners need to take in an organization, depending on factors such as organizational core task and culture, current level of safety, and external factors such as changes in legislative requirements or societal values. A weakness of the model is that it combines several different types of issues into one model, such as the goals of safety management in complex adaptive systems (*why, what*) and the working practices to reach those goals (*how*). The model also lacks guidance for selecting the concrete methods to facilitate and monitor the fulfilment of the principles (*what, how, when*). Finally, the model should offer holistic view of the various activities taking place in the organization, and their direct and indirect effects in order to avoid decomposition and reduction of the complex adaptive system into seemingly independent factors – with their linear causal effects.

In this paper we will describe the essential characteristics of "adaptive culture", present a revised model of adaptive safety management and discuss how the model can be applied in the context of safety culture improvement. We will focus on the following well-known approaches to safety culture management:

monitoring of the state of safety culture in the organization, bottom-up and top-down *safety-related communication*, and *direct behaviour modification*. A concrete safety culture improvement tool from each category is selected and examined from the perspective of the revised model of adaptive safety management. This exercise is intended to shed light on how conflicting safety management principles can manifest themselves in the concrete activities of safety practitioners, and highlight the paradoxical nature of these programmatic methods of changing complex sociotechnical systems. We propose that the utilization of this model in the practical implementation of safety culture improvement methods can help safety practitioners (especially middle-level) in high-risk organizations use these methods effectively and successfully.

2   ADAPTIVE SAFETY CULTURE

Resilience Engineering research tradition emphasizes that system safety is an emergent property of the system and should be seen as the system's ability to succeed under varying conditions (Hollnagel, 2011). Thus, system safety requires adaptive capacity. We argue that this adaptive capacity should be supported by what we call an *adaptive culture*. By adaptive culture we refer to an organizational (safety) culture that allows and supports qualitatively different – even contradicting – organizational manifestations of safety management (e.g. structures, tools, practices), depending on the anticipated and actualized needs of the organization. Adaptive safety culture embeds the assumptions that view safety systemically and as requiring a diverse means for managing it. The assumptions of an adaptive safety culture are not constraining even though its actions can sometimes be. An adaptive safety culture does not assume a command and control strategy as the preferred, or the only, way of managing safety, but it is still able to utilize those strategies when needed. An adaptive safety culture also needs to have the means to monitor itself and its adaptations (Hollnagel, 2011; Reiman et al., 2015; Reiman, Rollenhagen, & Viitanen, 2014). In summary, an adaptive safety culture should create the organizational preconditions to cope with anticipated and unexpected situations, and acknowledge the inherent adaptive nature of sociotechnical systems.

Adaptive safety culture becomes especially important in situations of external or internal change. For example, in an NPP construction project, a change in the lifecycle phase from design to construction, or construction to commissioning, requires both new types of activities, and changes to the existing activities. The same applies if there are changes in the project participants' safety culture. For instance, in early phases of the project, different methods are likely to be needed when the participants do not know each other, are not familiar with the specific requirements of the project, or do not have the necessary organizational preconditions in place. Once these have been established, the development of safety culture can proceed to utilize other types of methods and approaches. Alternatively, the methods can remain the same but they have different effect because the system has changed.

3   ADAPTIVE SAFETY CULTURE MANAGEMENT

3.1   REVISED MODEL OF ADAPTIVE SAFETY MANAGEMENT

In the revised model of adaptive management we included three tensions and a three-phase continuous improvement cycle (Figure 1). The selection of tensions is based on the assumptions that a complex sociotechnical system is multilevelled (i.e. involves upper and lower systemic levels), has the ability (and tendency) to self-organize, and involves interactions between multiple agents (e.g. Reiman et al., 2015). The first tension, levels of system goals, addresses the questions "*why*" and "*what*", and stems from the multilevelled nature of the system. This tension also involves the idea of temporality, namely that system goals are typically longer-term, and local goals are shorter-term. The second and third tensions represent safety management strategies, i.e. address the question "*how*". Each tension is characterized by contradicting safety management principles (the boxes in Figure 1). The model also embodies the idea that in order for the safety management to be functional in a sustainable manner, it must have the capability to utilize all of the principles, regardless of whether they are at odds with each other. This means that the tools (and the way in which they are) utilized by the safety practitioner should be sufficiently diverse in order to cover the whole spectrum of the model.

Including the three-phase continuous improvement cycle addresses the shortcomings of the previous model (chapter 1) and aims to answer the questions "*what*", "*how*" and "*when*". The cycle thus represents the kinds of actions that a safety practitioner can (and should) utilize for improving safety culture; furthermore, all three tensions influence (and are influenced by) the activities conducted in each of the phases. The continuous improvement cycle draws from concepts such as the Plan-Do-Check-Act cycle and the temporal elements of Resilience Engineering cornerstones (Anticipate, Monitor, Respond) and includes the following phases (with

descriptions of their meaning in the context of safety culture improvement):

- *Do and correct*: implement safety culture improving structures or influence behaviour of organizational members; correct or adjust those activities that have been found detrimental or ineffective for safety culture improvement

- *Monitor*: assess the basic assumptions regarding safety and their manifestations, including the way in which adaptations are made, what organizational structures are implemented and how they are utilized

- *Review and plan*: analyse the strengths and weaknesses from the results of past safety culture monitoring and implementation activities, anticipate future challenges and opportunities, and devise plans for future safety culture monitoring and implementation activities
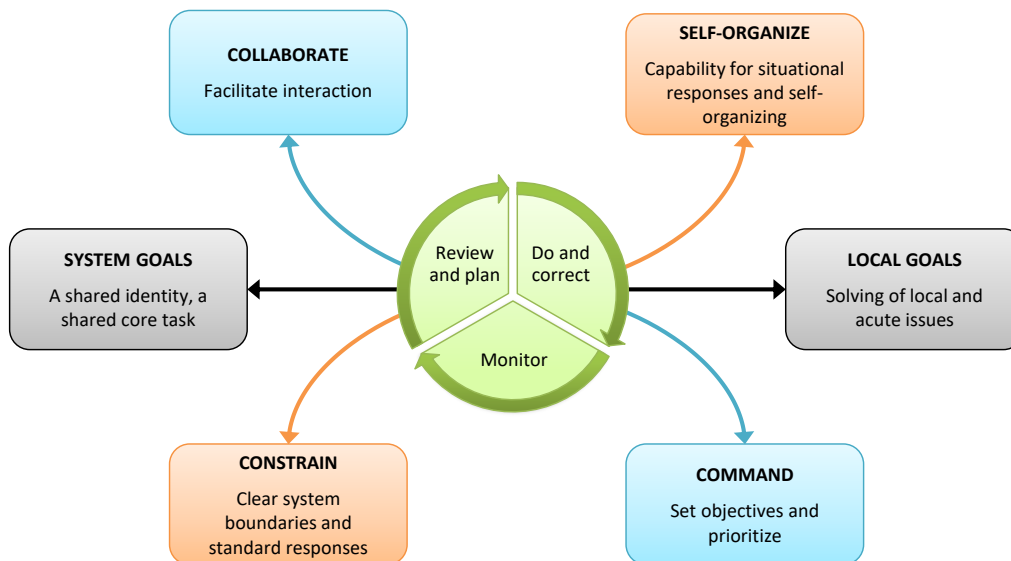

Figure 1. Revised model of adaptive safety management. The grey boxes depict the levels of system goals, teal and orange boxes depict the safety management strategies to achieve the goals. The arrows indicate the tensions between the system goals or strategies. The continuous improvement cycle in the middle depicts the kinds of concrete safety culture improvement actions taken by safety practitioners

3.2   SAFETY CULTURE IMPROVEMENT TOOLS

Audits (monitoring)

The use of auditing is a popular method for evaluating the extent to which a set of defined requirements is met. Audits are commonly used in the evaluation of management systems – either for internal development (i.e. internal audits), subcontractor evaluation (i.e. second-party audits) or for certification purposes (i.e. third-party audits). The requirements are defined, depending on audit type, either by internal company targets or by various standards such as the ISO9001 standard for quality management systems. To date, nuclear safety culture has rarely been evaluated by means of auditing. Audits as a safety culture evaluation method have been criticized as having excessive focus on structures and processes and not enough on how these structures and processes are applied in practice (e.g. Reiman, Pietikäinen, & Oedewald, 2008). However, there are cases where safety culture has been included in the audit agendas of safety management audits or quality standards. For example, the ISO9001-derived, nuclear-specific quality standard NSQ-100 includes requirements and guidelines for safety culture. Recently, audits have also been applied for evaluating safety culture in the nuclear industry supply chain (Reiman, Viitanen, & Koivula, 2017).

Reporting of near-misses and safety concerns (bottom-up safety-related communication)

Organizations aiming at a high level of safety strongly encourage personnel to report errors and near misses. Various types of reporting systems can by utilized for collecting information from the employees. The systems can be voluntary or mandatory, confidential or non-confidential. In this paper we focus on reporting systems that are voluntary and where personnel can make reports either with their own name or anonymously if they wish. Management uses the feedback received via the reporting systems to identify organizational problems and help individuals and teams learn from mistakes in order to perform better in the future. Documenting and

learning from patterns of failure provide free lessons for organizations that are successful in acquiring this kind of feedback (DoE, 2009, p. 95).

Safety training (top-down safety-related communication)

Safety training is likely to be the most commonly used practical method that has an explicitly stated focus of safety culture improvement. Safety trainings come in many forms and can range from short talks that are embedded within induction trainings or pre-job briefings, to extensive multi-week seminars and lecture courses on technical, human or organizational topics. Safety trainings serve many purposes depending on their content and focus. For instance, they can develop safety culture related awareness, behaviour or attitudes (e.g. Harvey, Bolam, Gregory, & Erdos, 2001; IAEA, 2002), and can be targeted at any level of the organization, including shop-floor, supervisors and middle management, and top management.

Human Performance Programs (direct behavioural modification)

The goal of a Human Performance Program (HPP) is to introduce and formalize a set of "good working practices", a.k.a. Human Performance Tools (HPTs), which are to be used by the members of the organization, typically shop-floor personnel (DoE, 2009; Oedewald, Skjerve, Axelsson, Viitanen, & Bisio, 2015). The HPTs are very heterogeneous and include practices such as Pre-Job Briefing (a meeting held before performing a given task), Post-Job Review (a meeting held once a given task is completed), Self-Checking (e.g. stopping to think and reflect before carrying out a task) and Clear Communication techniques (e.g. the use of three-way communication or phonetic alphabets) (see further descriptions in DoE, 2009). Usually the proclaimed objective of HPTs is to standardize working practices in order to avoid human error.

3.3   SAFETY CULTURE IMPROVEMENT TOOLS IN LIGHT OF THE REVISED MODEL

The safety culture improvement tools described in previous chapter are the concrete manifestations of the continuous improvement cycle. The segment "*do and correct*" includes, for example, the implementation or revision of an auditing process or a reporting system, conducting safety trainings, introducing a HPP, or using HPTs. Respectively, the segment "*monitor*" involves the use of auditing or reporting systems for information collection, gathering feedback from safety trainings (e.g. participant comments, test results) or from employees using HPTs. This means that the same tools can belong to both segments, but the "*do and correct*" phase is about implementing the tool and using it, while "*monitor*" phase is about receiving information about the organization or the tool's functionality. The segment "*review and plan*" integrates the information received from "*monitor*" or anticipates future requirements to produce a revision or a new plan for safety culture improvement, including the selection of tools and the way in which they are to be implemented.

The safety practitioner can utilize safety culture improvement tools to develop an adaptive culture by ensuring that the tools being used contribute to all of the principles of the model of adaptive safety management. An overview of the primary and secondary influences of the safety culture improvement tools, along with some insights regarding the factors to be considered when utilizing the tools, is presented in Table 1.

One of the main insights of this exercise is that *not all tools contribute to all principles* and that *some tools can contribute positively to one principle, but negatively to another*. For instance, audits, by definition, attempt to identify the non-conformities and deviations from requirements, thus focusing strongly on decreasing the self-organization and variability within the system (i.e. primary focus on "*constrain*"). On the other hand, due to the uniqueness of the characteristics of the operational environment of each auditee, certain level of local diversity (i.e. capability for "*self-organization*") may need to be retained. Thus, safety culture improvement through auditing may result in undesirable outcomes such as limiting the auditee's capability to cope with its inherent environment. Respectively, in the case of safety trainings, that can be utilized to disseminate and acculturate employees to company-wide practices or values, the focus is on ensuring that everyone contributes to achieving a common goal (i.e. contributes to "*system goals*"). Additionally, through the development of knowledge and skills, safety training can also result in the formation of, for example, a better understanding of the role of own tasks in relation to safety, the effects of humans and organizations on safety, and a wider understanding of the hazards that relate to the various organizational tasks (i.e. contributes to "*self-organize*").

A given tool can also contribute positively or negatively to a given principle, depending on how the tool is implemented. For example, at first glance HPTs may appear to focus on promoting repeatability and standard responses, and thus on limiting self-organization and system variance (i.e. "*constrain*"). However, in practice HPTs can also to contribute to safety by enabling knowledge sharing, improving the understanding of the work environment and sensitizing to the unexpected (Viitanen, Axelsson, Bisio, Oedewald, & Skjerve, 2015), and creating a shared culture (Viitanen & Oedewald, 2015). This means that HPTs can also be seen, for example, to

promote a shared identity and understanding of system goals, to create the capability for adaptation and to facilitate the interconnections between various organizational members (i.e. "*self-organize*", "*system goals*" and "*collaborate*"). The implementation strategy is one of the key elements that determine how the introduction of a HPP will end up affecting the system (Viitanen et al., 2015). For example, the communication of the content of the HPTs and the intention of their use, and their collaborative design together with the end-users have been identified as essential steps for the successful implementation of a HPP (Oedewald et al., 2015) (emphasizing the need for the principles of "*collaboration*" and "*self-organize*"). On the other hand, if too much lenience and decentralization is allowed in the implementation process, the benefit of HPTs as shared good practices might be reduced, which means that the safety practitioner needs to take the other end of these tensions (i.e. "*constrain*" and "*command*") into account during the implementation as well. This might involve, for example, sanctioning and enforcing the use of certain HPTs in certain situations.

A related insight is that the *tool may require the fulfilment of certain preconditions to be functional, or to function as intended*. For example, for a voluntary reporting system to function in practice, certain organizational characteristics are required. One of these preconditions is the creation of "just culture" (Reason, 1997), which involves the management getting the balance right between how unintentional errors and wilful violations are addressed in the organization (i.e. ensuring specific type of "*system goals*").

Table 1. *The influences of safety culture improvement tools on management safety principles*

Tool	Primary influences	Secondary / potential influences	Things to consider
Audits	Auditing contributes to **constrain** by verifying compliance against predefined standards or requirements	Auditing of safety culture can also be used to steer (**command**) the auditee to focus on the issues of interest to the auditor	Due to sample-based approach, auditing can contribute negatively to **local goals**, because it can lead the auditee to only focus on the issues identified in the audit
		Auditing can also be used to facilitate **system goals** by focusing on issues that are relevant based on the project's overall needs	The focus on **constrain** can hide the requirements of **self-organize**, and focus too much on structure instead of actual organizational potential
Reporting systems	Reporting systems contribute to **local goals** by encouraging and making it possible for the personnel to report near-misses and concerns they have about their own work	Reporting systems can also contribute to **self-organize** by pointing out issues in daily work that can be improved **System goals** can be facilitated by reporting depending on personnel's capacity to see the wider implications of daily problems	Reporting systems are dependent on **collaborate**. If there is a lack of trust and collaboration, they are likely to not function properly. A focus on **system goals** is required to establish a culture of trust and fairness The reporting systems may also further deteriorate **collaborate** if the personnel begins reporting minor issues that could easily be solved by communication and collaboration
Safety training	Safety trainings contribute to **system goals** by highlighting the importance of safety as a shared value and facilitating its formation through acculturation	Safety trainings can also contribute to **self-organize** by increasing knowledge and skills and widening the understanding of what safety means in a construction project	Using training as a safety culture improvement method can easily be interpreted by personnel as a **command** strategy if it is perceived as too one-sided
Human performance tools	HPTs contribute to **constrain** by promoting standard practices such as checking and verification practices, communication procedures, etc.	HTPs can also contribute to **self-organize**, e.g. by promoting STAR principle (Stop, Think, Act, Review) as a standard response or by facilitating learning through Post-Job Reviews	HPTs require some **command** to be fully implemented, yet their internalization and acceptance by the personnel requires **collaborate**. A heavy focus on only one of these two strategies will help in implementing the tools but may ultimately reduce the effectiveness of the tools

4 CONCLUSIONS

In this paper we have introduced the concept of adaptive safety culture, discussed its relevance in the context of NPP construction projects, proposed a revised model of adaptive safety management which explicates the safety management principles relevant to complex sociotechnical systems, and conducted an exercise that examines how practical safety culture improvement tools commonly available to any safety professional are related to the revised model of adaptive safety management. The revised model can offer several insights to safety practitioners aiming to improve the safety culture. These include:

- Highlighting the contributions that a given safety culture improvement tool has to the principles of adaptive safety management
- Helping identify the weaknesses of the safety culture improvement tools in relation to the other

safety management principles

- Highlighting the fact that all safety culture improvement tools embed certain principles yet these principles are interpreted by the safety professionals resulting in variability in the use of the tools in practice

In contemporary safety-critical organizations characterized by uncertainty and turbulence, utilizing an adaptive approach to safety management is especially relevant. By utilizing the revised model of adaptive safety management, safety practitioners can better plan, implement, monitor and review the activities conducted to improve safety culture in order to ensure that an adaptive safety culture is formed – one that embraces self-organization and collaboration, but also understands their limitations and is capable of utilizing the opposite strategies of command and control when needed.

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