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# Final report of MoReMO 2011-2012. Modelling Resilience for Maintenance and Outage

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## Abstract

The project Modelling Resilience for Maintenance and Outage (MoReMO) represents a two-year joint effort by VTT Technical Research Centre of Finland, Institute for Energy Technology (IFE, Norway) and Vattenfall (Sweden) to develop and test new approaches for safety management. The overall goal of the project was to present concepts on how resilience can be operationalized and built in a safety critical and socio-technical context. Furthermore, the project also aimed at providing guidance for other organizations that strive to develop and improve their safety performance in a business driven industry.

We have applied four approaches in different case studies: Organisational Core Task modelling (OCT), Functional Resonance Analysis Method (FRAM), Efficiency Thoroughness Trade-Off (ETTO) analysis, and Work Practice and Culture Characterisation. During 2011 and 2012 the MoReMO project team has collected data through field observations, interviews, workshops, and document analysis on the work practices and adjustments in maintenance and outage in Nordic NPPs. The project consisted of two sub-studies, one focused on identifying and assessing adjustments and supporting resilient work practices in maintenance activities, while the other focused on handling performance trade-offs in maintenance and outage, as follows:

A. Adjustments in maintenance work in Nordic nuclear power plants (VTT and Vattenfall)
B. Handling performance trade-offs - the support of adaptive capacities (IFE and Vattenfall)

The historical perspective of maintenance and outage management (Chapter 1.1) was provided by Vattenfall.

Together, the two sub-studies have provided valuable insights for understanding the rationale behind work practices and adjustments, their effects on resilience, promoting flexibility and balancing between flexibility and reliability.

## Key words

Resilience engineering, adjustment, work practice, maintenance, outage, field operators, organizational core task, safety culture, trade-offs

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# Final report of MoReMO 2011-2012

## *Modelling Resilience for Maintenance and Outage*

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# Contents

# 1 Introduction

Maintenance is a critical activity in nuclear power plants as it provides the technical preconditions for safe operation of the plant. Maintenance activities include heterogeneous set of tasks with varying degrees of technical demands, safety significance and inter-couplings. In the nuclear industry, complexity stems from the hazards and technical complexities, the work procedures and the social organisation. The annual refuelling outages in particular pose certain challenges because the complexity of the social organisation of maintenance and operation increases in comparison to normal operation. This is due to the substantial number of tasks, time pressure, and a large number of external inter-connections with, e.g., contractors and suppliers. Even though outages are planned in great detail and well in advance, there is a constant need to adjust the schedule to emerging issues. Accident investigations reveal that in various safety-critical domains, i.e. railway, offshore oil drilling, chemical, petrochemical, aviation and nuclear industries, inadequate or faulty maintenance is one of the main contributors to events (e.g. Reason, 1997; Hale et al., 1998; Kletz, 2003; Reason & Hobbs 2003; Perin, 2005; Baker, 2007; Sanne, 2008a). The master schedule usually contains slack time and resources to accommodate minor deviations. However, additional re-planning and problem solving often occurs that goes beyond modifying the master schedule. Since the duration of the outage has direct financial implications for the owners, there is a strong incentive to keep outage delays to minimum.

Traditional safety management approaches emphasise thorough preplanning and compliance with procedures. However, in complex activities such as maintenance, unexpected situations are frequent, and often people need to proceed in their work tasks without clear-cut procedures. Maintenance personnel have to adjust to unexpected situations without even noticing this. However, we think that successful adjustments are source for organizational learning and development. In the MoReMO project we tried to understand what can be learned from the adjustments in everyday maintenance settings, and how they can be used to further develop and improve the work practices.

## 1.1 Is the current approach for safe management of maintenance and outage enough? A historical perspective

The current dominant approach in safety management is to strive for control by describing the most safe and effective way to perform activities. The foremost applied approach is through regulation, featuring a high grade of detailed procedures of activities and generalization of rules. However, experiences from safety work in high-complexity organizations suggest that this approach has its limitations.

**The heritage of past production management – Scientific management**

The origins of current production management approaches can be found in the concept of Scientific Management, later known as *taylorism* after its well-known originator Frederick W. Taylor. The idea of taylorism was first presented in the early 1900's and the purpose was to make the growing industry more effective. According to Taylor, this could be achieved by introducing strict control and scientific metrics into production management. Developments of his ideas laid the ground for automation, for example in the production of automobiles (*Fordism*) and the concept of MTM (*Methods-Time-Measurement*). In MTM, every single action and its duration was broken down in detail, measured and regulated. "*Best practises*" is another important concept within scientific management, which is used to model the one optimal way to perform a task.

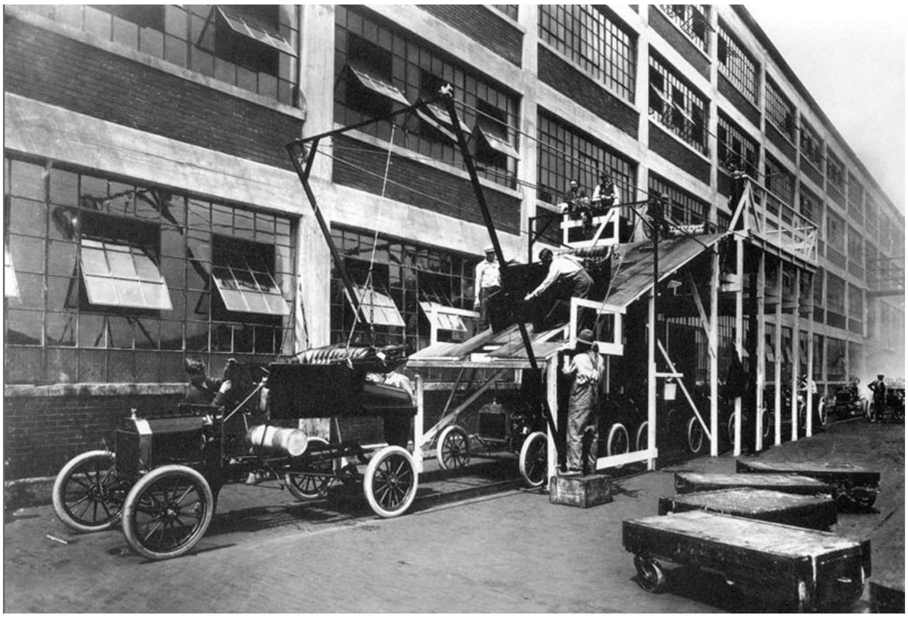

**Figure 1. *1913* – Early assembly line at Ford factory.**

Taylor's principles became guiding for the way the production industry – and later also non-industrial settings – developed their organization of work. We suggest that many of these principles still live in the management of safety-critical organizations of today.

The essence of scientific management is illustrated by the following (Taylor, 1911):

> *"The development (by the management, not the workman) of the science of any task, with rigid rules for each motion of every man, and the perfection and standardization of all implements and working conditions."*

This means that the management was considered more knowledgeable of the work processes than the workers. The managers thus defined the rules, regulations and methods for work execution. Standardization was emphasized: There is only one optimal way to perform a task and it should be adhered to. Thus the most effective production, or in our context safety, could be achieved. This could be translated into the motto "Follow the rules". Virtually no room – nor means – is left for adequate adaptations on the workers level when this is demanded by the situation. In the perspective of the demanding complexity of today's socio-technical organizations this view can become a limitation for an adaptive safety management approach.

It should also be mentioned that Taylor pointed to the importance of selection and training of workers (as well as the exclusion of non-performers who cannot adapt to the best methods). Also emphasized was the close cooperation between managers and workers to support and develop task performance.

Taylorism is sometimes criticized for alienating workers; "the worker was taken for granted as a cog in the machinery" (Rosen, 1993), treating them as mindless, emotionless, and easily replicable factors of production (Greiff, 2003). Workers mandate, initiative and creativity is replaced by oversight control and regulation by a concept. That may explain why flexibility, manageability and adaptation are so undeveloped – and changing one concept for another one does not help since vertical information transfer (top-down) remains prominent over horizontal communication (Wennberg, 2007). Our thesis is that this kind of management can be highly inhibiting for flexibility and creativity on the work floor.

## The heritage of past human performance management and means for control – Behaviorism

Another important approach still influencing managerial methods of today is *behaviourism*, which very origin can be tracked as far as to Pavlov's research on animals. Skinner, as an American psychologist, further developed the theories of behaviourism (Skinner, 1938). A topic of interest for our perspective is his concept of positive and negative reinforcement for influencing human behaviour. Taking learning as an example, behaviourism focuses on a change in external behaviour through a large amount of repetition of desired actions, the reward of good habits and the discouragement of bad habits. In the classroom this view of learning led to a great deal of repetitive actions, praise for correct outcomes and immediate correction of mistakes. The conceptualization of learning using this approach could be considered "superficial" as the focus is on external changes in behaviour. There is little interest in the internal processes of learning leading to behaviour change. Amongst practitioners this view has largely formed the way human behaviour is understood, managed and evaluated within human performance improvement and safety management.

Figure 2. 1944 – The ruling teacher "Caligula", from the Swedish film "Torment" © AB Svensk Filmindustri.

Even today the ideas based on taylorism and behaviourism live in the industrial organisations, especially when organisation define strategies to improve quality and safety by strict procedures and instructions and thus aim to prevent human errors. This can be exemplified by current "Safety management" paradigms – manifesting in Best practice, Corrective Action Process (CAP), Failure Mode Effects Analysis (FMEA), Human Reliability Analysis (HRA), detailing by procedures, hierarchical organizations and top-down structures – which try to define, regulate and control every possible state in a process or activity.

The research in human behaviour, organisations and complex systems has questioned the benefits of taylorism and behaviourism in management of modern organisations. One of the main arguments is that such a view does not take into account the need for continuous adjustments and innovation which are also important for coping with the unexpected situations created by the complexity as well as for continuous learning.

Some maintenance work-packages are less descriptive, less information-rich, than others. Still, the workforce is implicitly expected to handle on-the-spot adaptations, regardless of the knowledge and experience levels of individuals. This indicates presence of a belief in regulation, an implicit understanding that this is not always met, and an implicit trust in informal adjustments, consequently not actively utilized and managed.

Procedural adherence is regarded as one of the main safety mechanism to achieve desired outcome in operator actions (*safe and reliable operation*). However, a questioning attitude is also expected to be demonstrated at all times. Nevertheless, the reliability of this type of barrier is ad hoc based by nature. This is because it is tied to the individual understanding of the unexpected. This in turn depends on availability of information, organizational structures, experience, tacit knowledge, a judicious mindset, social interactions, culture, norms and climate. Given a world of complexity and variability, to manage all the safety-critical aspects within a socio-technical environment is indeed a vast challenge.

**Future safety potentials**

Organizations strive for control by applying a simplified view on safety management. As exemplified above, this approach has its limitations. Organizations standardize in the spirit of best practice to define the optimal way to perform a task, leaving little room for adjustments. Adaptations to cope with work demands are made on local level. These adaptations are often unsupported, unguided and to some extent regarded as non-compliance which may be subject for correction. Successful safety management of today would therefore likely demand a reconsideration of old paradigms and the adoption of new ways of thinking. Deterministic approaches would give way for models accounting for *uncertainty*, the presence of *performance variability* and thus the need for *continuous adjustments*. As today's complex organisations are practically impossible to predict and manage in detail, it is not worthwhile to try to control them in the traditional sense of the word. Rather they should develop their resilience in order to deal with up-coming surprises in the best possible way.

In order to improve the ability for a system to adjust its functioning to changes and disturbances, we need to gain a better understanding of real-life working practices and adjustments in their natural environment and actual everyday work situations. Therefore, we acknowledge the importance of focusing on the practice of maintenance and field operation during outage and explore it from a resilience engineering perspective.

## 1.2 Resilience engineering as a framework for dealing with complexity and variability

Resilience Engineering approach aims at providing novel insights on the safety management of complex industrial systems (Hollnagel, 2009b). One of the premises of Resilience Engineering is that safety research should pay more attention to everyday activities in the organisation and learn from *what goes right*. Despite the Resilience Engineering literature does not include work practices as one of its key theoretical concepts, *everyday performance* is usually referred to as the focus of analysis of this approach (Hollnagel, 2009b). The concept of everyday performance includes the notion that in an organisation certain ways of working and certain activities tend to occur in similar ways during the time and become the "normal" way an organisation, and people in the organisation, decide to accomplish work scopes. Learning from incidents and accidents is important, but in terms of safety development understanding everyday successful activities is also very important.

Resilience Engineering acknowledges that local adaptations and human performance variability are not necessarily threats to safety and reliability. Instead, adaptation and performance variability are necessary because they allow the system to function as smooth as possible and to respond to unexpected challenges. Resilience Engineering looks for ways to manage organisational safety (Dekker, 2006) and to enhance the ability of organisations to monitor and revise risk models, to create processes that are robust yet flexible, and to use resources proactively in the face of disruptions or on-going production and economic pressures (Woods et al., 2010). A plurality of definitions for resilience can be found in literature. Leveson et al. (2006) define resilience as the system capability to prevent or adapt to changing conditions in order to preserve its control over a system property. Loss of control and erosion of safety margins are some of the problems organisations could face in their tentative to adjust their operations under both expected and unexpected conditions (Hollnagel, 2009b). Hale et al. (2006) describe resilience as the ability an organisation must have to manage the conflict between safety efforts and production efforts.

### Abilities of resilient organisations

Resilience Engineering aims to increase the capability of organisations in making appropriate adjustments needed for ensuring its normal functioning. Understanding the key abilities that constitute the normal, productive functioning, including the coping ability, is therefore a requisite for implementing the Resilience Engineering approach and, by doing so, supporting both protection (safety) and production. Successful adjustments imply that the organisation is able to respond to the challenges and disturbances as they come along. The possibility to perform successful adjustments is increased if the organisation is able **to monitor** and foresee which problems and opportunities can potentially arise in the future. Monitoring the organisation's own performance and essential operating conditions allows identifying what could be critical in the near future. The ability to do it in a flexible manner and taking into consideration the variability of the organisation's performance will enable the timely deployment of preparatory measures. Such preparatory measures will support the performance of smooth adjustments in the case that the critical conditions actualise. Anticipate opportunities, threats, disruptions and destabilising conditions is at the basis of the ability to deal with irregular, possibly unexampled, events. The ability **to anticipate** implies having the requisite imagination for seeing what may happen in the future and its key aspects. This requires going beyond risk analysis and identifying not only single events, but also how different events may interact and affect each other. At the same time an organisation that is able to continuously learn from its own and others' experiences is more likely to have developed and implemented means to effectively sustain its operations. Understanding what happened and why is at the basis of the ability **to learn** from experience. This requires selecting both learning sources (from where to learn) and learning contents (what to learn) as well as using what learned for implementing improvements to procedures and practices. For an organisation, to be able to learn, monitor and respond means that it will be better prepared to deal with regular or irregular threats. As a matter of fact, despite the efforts in learning, monitoring and anticipating, any organisation is inevitably designed for responding to a limited set of events and adjustments to meet actual challenges that occur regularly. **To respond** to regular and irregular threats in an effective, robust and flexible way constitutes the ability of an organisation to cope with variable operating conditions (see Fig. 3).

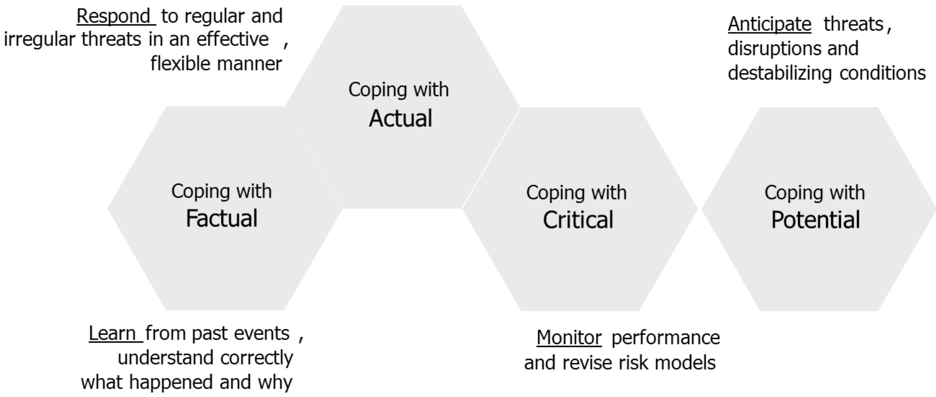


**Figure 3. Abilities of resilient organisations (adapted from Hollnagel, 2009b).**

The adjustments an organisation performs can take place in reaction to something that has occurred, in response to something that is occurring or in prevision of something that may happen in the future (Hollnagel, 2009b). While the first ones are the most common to happen, as in the aftermath of an incident or as result of the learning process, and the second ones basically provide the flexibility for sustaining operations under disturbances and disruptions, proactive adjustments prepare the organisation for better coping with conditions that are expected to happen in the near and far future.

Woods (2009) sees resilience as a second-order property, i.e., the ability to maintain and adapt the capacity to learn, monitor, anticipate and respond in a resource-constrained environment that changes in the short as well as the long term. Thus, to mobilize additional resources when a system reaches its margin of manoeuvre is one of the essential mechanisms for maintaining resilience.

Woods (2009) proposes that when a system functioning is optimized with respect to some events or uncertainties in the environment, the system will be more brittle when exposed to novel events and uncertainties outside the design basis. Thus, resilience and brittleness are parameters to assess the extent to which a system can handle events that challenge the boundaries of operation. The boundaries may be challenged when plans and procedures do not cover all aspects, because the system or the environment changes. The capacity to meet novel events resides in expertise and tools that people can utilize to stretch the system, for example by developing new strategies, reorganize the work and mobilize additional resources. To balance and prioritize concurrent goals is a daily task for any outage and maintenance organization. Procedures, schedules and work practices are all tools that help optimize one or several objectives. During an outage, several considerations have to be taken into account: efficiency, resource availability, nuclear safety, occupational safety and costs. A dilemma arises when multiple goals cannot be met concurrently. The situation is aggravated when the criteria for each goal are unclear, where clear rules or guidelines for prioritizations are lacking, or when it is unclear if a goal can be achieved. Whenever two or more goals are in conflict, the individual may have to make a trade-off decision, sacrificing in how well one or all goals can be achieved, or mobilize additional resources to achieve both goals. In some cases, the cost of sacrificing a goal is potential or probabilistic. Organisations could in principle allocate resources to maintain and improve all the resilience abilities (ability to learn, ability to respond, ability to monitor, and ability to anticipate) at the same time. In reality, due to temporal and economic constraints, allocation of resources is done according to the organisation's priorities.

The *ability to respond*, also called "real-time resilience", appears to be particularly relevant for maintenance and outage organisations, which inevitably have to deal with uncertainties and for which solving problems is part of their task. Through the performance of successful adjustments (e.g. revising plans when something unexpected happens) maintenance and outage organisations are able to accomplish their aims. It should therefore be of particular interest for maintenance and outage organisations to support flexibility and successful adjustments while at the same time remaining in control of the situation. To do so, maintenance and outage organisations should identify and describe successful work practices that balance the needs for flexibility and reliability.

# 2 Study A: Adjustments in maintenance work at Nordic nuclear power plants

The aim of this study is to identify adjustments in maintenance work at the Nordic nuclear power plants and evaluate the contribution of the identified adjustments to resilience of maintenance. A further aim is to provide guidance on developing resilient work practices based on the insight from the analysis of the identified real-time adjustments. Accordingly, the research questions of this study are as follows:

- How to describe work practices and identify adjustments?
- How to assess the adjustments in terms of their contribution to resilience of the plant?
- How to develop resilient work practices?

The practice of maintenance and outage is composed of a range of activities, which are composed of tasks. In the common sense, the term practice refers to any kind of usual way of carrying out tasks. Researchers, on the other hand, have tried to define what constitutes practice. According to Norros (2004, p. 66), *practice* indicates a coherent and complex form of socially established co-operative human activity that expresses the societal meaning of actions and thus is part of the culture of the community. Overall, practices are seen as patterns or "meanings in action" (Norros, 2004, p. 79). Although actions are similar to practices, not all actions are practices as not all of them are meaningful. *Actions* are simply observable individual behaviour, whereas *practices* are cooperatively and historically formed, i.e. in order to notice and observe a practice, some interpretation is needed. In other words, identifying practices means distinguishing generic dispositional features of behaviour, and revealing the meaning of the practices requires connection to the objectives of the activity.

Some scholars describe practices as skills or knowledge that 'underpin activities' (Schatzki 2001, p. 2), while others see them as routines (Reckwitz, 2002). "Practice" as knowledge pinpoints to knowledge/understanding as constructed in cooperation with others and through relationships with the tools and symbols that characterize the setting. "Practices" as routines consist of several interconnected elements: forms of physical and mental activities, tools and their use, know-how, states of emotion and knowledge (Reckwitz, 2002, p. 249). Overall, the existing definitions of practice emphasise that work practices do not develop randomly but there are reasons why things are carried out in a certain way in the organizations. In a way, practice theory is a type of cultural theory as it looks at practice as a patterned way of behaviour, which encompasses some underlying assumptions, norms and meaning.

For the purpose of this study, we define *work practices* as the typical ways of doing something in terms of everyday maintenance activities (such as e.g. acquiring spare parts or getting a work permit) in a given organizational culture. We define an *adjustment* as an ad-hoc adaptation to an underspecified, unexpected situation, which represents a modification of the way the planned task is executed to reflect the actual conditions. For instance, an adjustment is when some tool does not work properly and the maintenance personnel decide to borrow similar tool from a subcontractor company in order to get the job done. We understand work practices as manifestations of the organizational culture while adjustments and ad-hoc decisions are influenced by the organisational work practices. The same adjustments and ad-hoc decisions have the potential, if frequently repeated, to be incorporated in the organisational culture and themselves become practices. In this project we have used the work practice approach to better understand adjustments in maintenance activities and to further improve work practices. This is in line with the current safety theories, which emphasise that timely and risk-informed adaptations are key elements for the efficient and safe functioning of organisations when coping with disturbances (Hollnagel, 2006).

## 2.1 Methods and Research Strategy

To study resilient work practices and adjustments in maintenance activities in Nordic nuclear power plants, we adopted a multiple case study research design. For the four case studies we conducted, the data collection methods included pre-observation document review of the work scope, field observations, document analysis, semi-structured interviews and workshops. The observations aimed at identifying practical ad hoc decisions, local adaptations and their backgrounds. Two or three researches observed selected outage jobs for one or two days. During the observations the researchers also interviewed workers and photographed the work environments and work situations, when possible. The observations were used to gain insight on organisation's way of handling everyday challenges and ability to take into account outage organisation's core task demands.

Data collection was complemented by interviews with personnel from the plants. Interviews were carried out to clarify the safety relevance of the work being observed, the background information concerning selection of the working group and informing on the possible challenges in the course of work. The semi-structured interview scheme was designed to discuss the core task of the maintenance organisation during normal operation and during outage, to allow exploring the requirements for performing daily work, perceived specific pressures and constraints, and strategies for preparing for them and for coping with underspecified situations.

In total, eleven days of field observations were conducted, thirty-three maintenance personnel were interviewed, internal research workshops and seminars were held, and documentation (e.g. maintenance handbooks) was analysed. The data collection in each of the four case studies was focused on selected relevant maintenance activities. The selection of what to observe and about what data to collect has been greatly influenced by the on-going maintenance activities at the time of the observations.

Conducting observation meant for researchers to spend time in the actual work setting and record what occurs, take notes concerning on-going activities and their contexts. During the different case studies we had the opportunity to follow and observe various maintenance activities. We had the opportunity to witness what the maintenance personnel did and how jobs were performed, e.g., how tools were used, how communication took place and how decisions were made. Interviews and workshops allowed the clarification of some of the technical details, and helped researchers in collecting data about and making sense of the observed maintenance activities. Through the interviews and workshops we had the opportunity to gather information about how maintenance personnel experienced the challenging situations, what, from their perspective, created the need for adjustments, and how maintenance work is normally organised and performed in their own organisation.

To frame our work, we focused on challenging situations in which maintenance organisations had to solve unexpected problems by making ad-hoc decisions. The identification and description of adjustments was done by observing maintenance field works, interviewing maintenance personnel, and making sense of the collected data with the support of the modelling technique Functional Resonance Analysis Method (FRAM) (Hollnagel, 2004, 2012; see Appendix A3), and the cultural perspective (Reiman & Oedewald, 2009). Applying the cultural perspective on the adjustments means focusing on the prevalent mindset of the maintenance organisation, the systems and structures which create preconditions for high quality work, and the individual and organizational knowledge and understanding of the hazards and safety consequences of the work (Reiman & Oedewald, 2009). According to the cultural perspective, the work practices can be seen as manifestations of the organizational culture, which frame behaviours and situational decisions, taken in real-life activities. Culture manifests itself in the structures of the activities, such as resources, working arrangements and instructions. Furthermore, culture sets social norms, defines what is considered important, how goals are prioritised and what the status of different groups is. The psychological states and the conceptions of individual workers are affected by the culture prevailing in the system as well, e.g. feelings of being in a hurry or perception of risk in certain situation are largely dependent of the safety culture of the organisation.

## 2.2 Identification and assessment of adjustments in maintenance activities

We focus on identifying and assessing adjustments in terms of their contribution to resilience of the plant because the ways of making successful resilient adjustments could be then gradually turned into habitual work practices to further increase the resilience of the system in the future. Practices are habitual in the sense that they carry meaning (Norros, 2004), which is not necessary truth for situational actions. The habitual aspects of practices do not equal mechanical repetition; rather, they enable continuity in adjusting to the changing environment. The challenge is how to evaluate whether a specific adjustment has been resilient or not. A sound set of criteria is needed for evaluation of the identified adjustments.

### Development of criteria for assessing adjustments

We developed three types of criteria to assess the adjustments from the perspective of their potential contribution to the overall resilience of the plant, and divided them in three sets. Our evaluation criteria are developed and built upon multiple theoretical frameworks and approaches as the core task analysis conceptualization and its application to qualify practices (Norros, 2004), operationalization of organizational culture and organizational core task in maintenance organizations (Reiman, 2007), organizational core task (OCT) modelling approach (Oedewald & Reiman, 2007) and the Design for Integrated Safety Culture (DISC) model (Reiman & Oedewald, 2009; Oedewald et al., 2011).

The **first set of assessment criteria** refers to organizational orientation towards its *critical core task demands*. The idea is that an adjustment may look problematic or like a deviation from the plan, but as long as it contributes well to the organisations overall core task or goal, it can be considered good and resilience enhancing. Based on the modelling work done in *expert group meeting*s with experienced nuclear power researchers and power plants representatives, the following six OCT demands for maintenance during the outages were theorized (see Fig. 4):

1. Planning of the tasks, schedule and resources (which need to be as complete beforehand as possible)
2. Coordination of the activities with the other parties (needs to be continuous)
3. Monitoring of the plant condition while performing any tasks (needs to be a shared task)
4. Knowing what is essential in each technical system one works with and knowing what might be the (safety) consequences if the work does not succeed
5. Prompt reacting to unexpected findings at the plant
6. Allocating resources in a flexible manner, redirecting attention and resources from task to another

More specifically, based on our OCT modelling approach, we defined the core task of maintenance during outage as ***to provide technical conditions for effective and safe operation of the plant until the next scheduled overhauls and fuel load***. Maintenance includes tasks such as fuel reload, periodical inspections, planned overhauls and fixing detected faults.

As depicted in Figure 4, the OCT demands concern both expected and unexpected situations and different phases of maintenance activities, i.e. before, during and after outage.

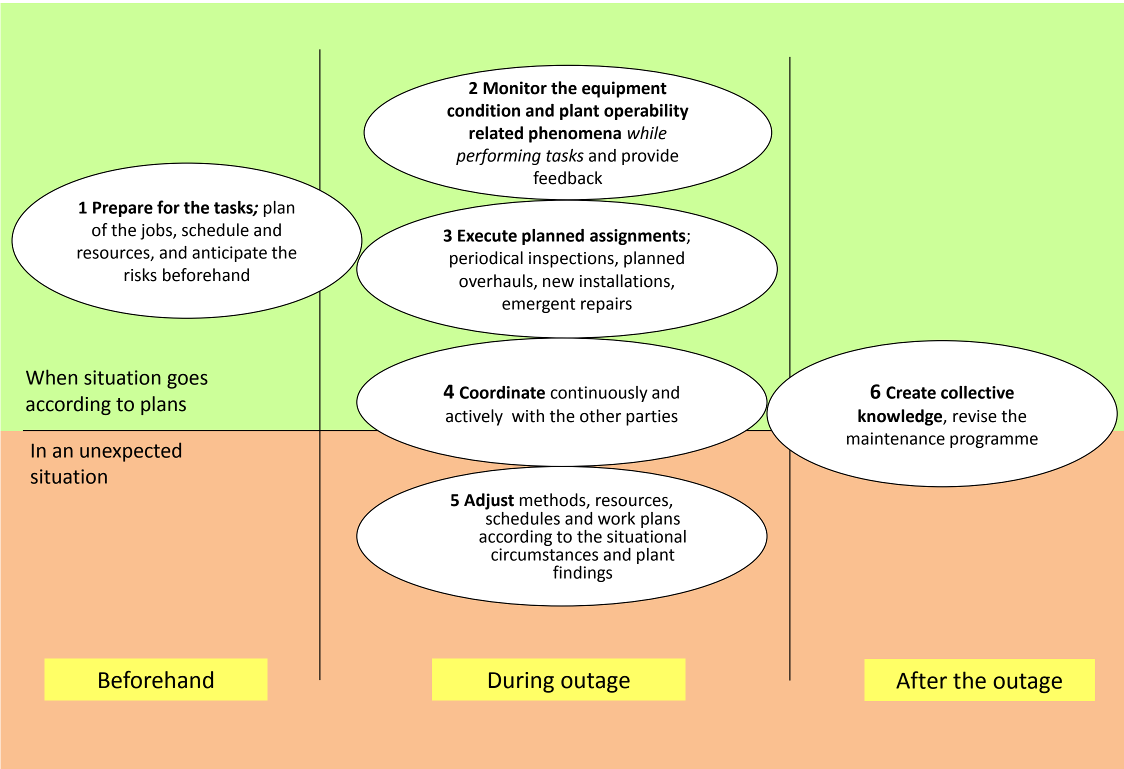


**Figure 4. Critical core task demands for maintenance organization performing the outage.**

The evaluation principle of the criteria "critical core task demands" postulated that **if the activities of an organization are focused or oriented towards at least one of the above listed core task demand, and if the activities are performed in such a way that indicates keeping in mind the rest of the demands as well then the activity is considered acceptable for the**

**resilience of the system.** It should be noted that while focusing on one of the demands, organizations are not allowed to clearly violate some of the other five demands.

To illustrate the use of the assessment criteria based on the OCT modelling, we will provide two representative *hypothetical* opposing examples: first, we will give an example of an episode where maintenance personnel did not fulfil any of the core task demands, and second, we will describe an episode which looks like the maintenance personnel is not perform according to core task demands but actually our model shows that they are doing the right thing:

Hypothetical example 1: *The maintenance personnel is discussing and planning certain task to a certain degree, then change some aspects and planning again but have never taken any concrete actions to actually execute the planned task.*

This episode looks like there is intention to fulfil the preparation core task demand but it stops there without fulfilling any of the core task demands.

Hypothetical example 2: *A group of subcontractors is walking in the corridor when suddenly pays attention to an unusual smell or noise. The workers become active, begin asking questions, spend time and energy to notify whoever they think need to be informed, although this is not part of their work scope. Besides, their actions revealed that they have kept in mind also the need to coordinate with other parties, they have adjusted their own task in relation to this unexpected finding, as well as they created good preconditions for creating common knowledge.*

At first sight, this episode could be interpreted as these workers are interfering into someone else's work scope, or their line of responsibilities is unclear. However, a closer look indicates that they are actually doing the right thing because noticing something strange and providing feedback is considered evidence of fulfilling the monitoring core task requirement, which should be everybody's responsibility.

The **second set of assessment criteria** was also developed as a result of the OCT modelling to provide more detail and to complement the generic core task demands. *Work practice demands*, which correspond to each of the core task demands, represent specific daily activities the maintenance personnel should perform to fulfil the core task demands. The evaluation principle of the criteria "work practice demands" postulated that **if the activity meets at least one work practice demand and if the activities are performed in such a way that indicates keeping in mind the rest of the demands as well then the activity is considered acceptable for the resilience of the system.** The work practice demands (see Table 1) were defined separately for each critical core task demand, thus not all of the work practices demands should necessarily make sense if the workers are aiming at fulfilling a certain critical core task demands. Work practice demands were identified by the research team during a two day workshop on the basis of the analysis of the data collected during observations and interviews, and of researchers' knowledge and experience of the maintenance work in nuclear power plants.

**Table 1. Critical core task demands and the corresponding work practice demands for maintenance organisations.**

| Critical core task demands | Corresponding work practice demands |
|---|---|
| **Preparing for the tasks**; planning of the jobs, schedule and resources, and anticipating the risks *beforehand* | • Aim to take the different stakeholders into account in the plans<br>- Involve different parties in the preparations, collaborate & consult<br>- Identify the relevant expertise needed in the work to ensure success in contracting process<br>• Utilize past experiences, screen documents, etc.<br>• Analyse the nuclear safety significance of the work tasks beforehand and document that<br>• Reserve slack resources, prepare for unexpected<br>• Finish the master schedule timely/early<br>• Acquire of tools, papers, spare parts, etc. well beforehand and carry out readiness review |
| **Monitor the equipment condition and plant operability** related phenomena *while performing* tasks and provide feedback | • Pay attention to anything unusual even outside your work scope, show interest towards technical issues (walk eyes open)<br>• Ask questions<br>• Report findings and reward people for reporting<br>- Participate to face to face forums where feedback can be given<br>- Utilize of maintenance history database (or similar ICT system for giving feedback on the technical issues) |
| **Execute planned assignments**; periodical inspections, planned overhauls, new installations, emergent repairs | • Check the plans, in e.g. pre-job-brief<br>• Aim to accomplish the task, put effort in getting the work done, be active<br>• Adhere to schedules, specifications of quality parameters, materials and tools, and specific instructions on conduct of work (if available), and generic principles of safe work<br>• Take others' work tasks into account while performing yours |
| **Coordinate** continuously and actively with the other parties | • Learn to know others whose work task relate to yours<br>• Explain what you are doing and what is relevant in it, make sure other stakeholder know the risks<br>• Report progress and delays<br>• Use multiple communication channels: phone calls, meetings, informal channels<br>• Intervene and help out if other work groups are struggling with their work |
| **Adjust** methods, resources, schedule and work plans according to situational circumstances and unexpected plant findings | • Evaluate the safety impacts of any change in your work process<br>– Involve engineers, work managers or other experts in the evaluation<br>• Be prepared to respond to local work circumstances. Learn how to:<br>– Stop and reschedule the ongoing work<br>– Move to another, more urgent work scope<br>– Cancel the work order<br>– Utilize quick work order process to start new work<br>– Change the work, method tool or material<br>– Inform others on the changes |
| **Create collective knowledge**, revise the maintenance programme | • Analyze whether the preventive maintenance programme of each system is valid based on the information received during the outage<br>• Analyze whether the maintenance instructions were sufficient and correct for the workers |

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| | • Utilize the know-how of the shop floor personnel<br>• Analyze if the adjustments made during the work were based on solid understanding of the work requirements |

The core-task orientation of the maintenance organization is not enough to ensure good resilience because it is not only what they do, but *how* they do it that is important for resilience, and here is where the focus on safety needs to be demonstrated. The idea is that an adjustment may look problematic or like a deviation from the plan, but as long as it contributes well to the organisation's overall core task or goal and is carried out according to good safety culture, it can be considered resilience enhancing. Therefore, we developed a **third set of assessment criteria**, based on the *safety culture* approach and more specifically, on DISC model (Reiman & Oedewald 2009; Oedewald et al., 2011). The DISC model describes six criteria for good safety culture:

1. Safety is a genuine value in the organisation which reflects in decision making and daily activities;
2. Safety is understood as a complex and systemic phenomenon;
3. Hazards and core task requirements are understood thoroughly;
4. Organization is mindful in its practices;
5. Responsibility for the safe functioning of the entire system is taken;
6. Activities are organised in a manageable way.

According to the DISC model, when an organization meets *all* six criteria, it is supposed to have a good potential for safety or good safety culture. Each safety culture criterion should manifest itself in the organisational structures and systems, in the workers' psychological experience and perceptions of organisational practices, and in social norms and practices (Oedewald et al., 2011). The six criteria imply that safety conscious mindset or good systems and structures which create preconditions for high quality work are not sufficient for ensuring a good safety culture, the individual and organizational *knowledge and understanding* of the specific hazards and safety consequences of the work play a key role as well. The evaluation principle of the criteria "safety culture criteria" postulated that **if the activity is performed without explicitly violating any of the safety culture criteria, then the activity is considered acceptable for the resilience of the system.**

### Results from the application of our assessment approach

We carried out field observations and interviews, from which we selected five interesting and fruitful episodes to exemplify the application of our assessment approach (see Table 2). We based our assessment on the criteria deduced by the OCT modelling approach (respect of core task demands and work practice demands) and the DISC model (respect of safety culture criteria).

The evaluation of adjustments with respect to their potential contribution to the resilience of maintenance organisations utilises the sets of evaluation criteria previously introduced. The logic which has been applied in the research project for evaluating the field observations can be explained as follows. For each adjustment we observed, we have been questioning if its execution aimed at fulfilling any of the six core task demands identified in the OCT modelling. This provided a preliminary understanding about the coherence of what observed with the overall mission of the maintenance organisation, i.e. its core task. It is unlikely that an adjustment which clearly does not contribute to the core task can support the resilience of the maintenance organisation. On the other hand, an adjustment which helps the maintenance organisation in fulfilling its mission is potentially supporting resilience. For a more detailed evaluation of the observed adjustments we have been also considering how adjustments met the work practices demands. In order for an adjustment to support the resilience of maintenance organisation it has not only to serve the mission of the maintenance organisation, but its performance has also to satisfy the work practice demands associated to the corresponding core task demands. Finally, we evaluated adjustments on the basis of how they were performed. The safety culture criteria were used for this purpose. While the evaluation based on the core task and work practice demands considers if an adjustment in principle aims at the appropriate objective and it take into account the work practice demands, the evaluation based on the safety culture criteria consider if its execution does or does not, in practice, violate any safety culture principle. An adjustment that despite being performed with the "right" intentions is executed infringing the fundamental safety culture criteria is unlikely to actually contribute to the resilience of maintenance organisation. The logic that guided our evaluation of the field observations can be summarised as:

- Adjustments which are performed taking into consideration only one out of the six core task demands without at least keeping the rest of the demands in mind do not contribute to the resilience of the maintenance organisation, i.e. they are potentially risky.
- Adjustments which do not meet at least one or more work practice do not contribute to the resilience of the maintenance organisation, i.e. they are potentially risky
- Adjustments which explicitly violate any of the safety culture criteria do not contribute to the resilience of the maintenance organisation, i.e. they are potentially risky.

**Table 2. Assessment of selected observed adjustments.**

| **EPISODE 1** | |
|---|---|
| Description of the observed episode | The testing procedure involved pressure test of a subsystem, therefore injection of water in the circuit was initiated but the pump did not work properly. The contractor wanted to proceed to the next steps of the testing in the evening. The contractor fetched a new pump which functioned at the beginning. As pressure has been rising, the supervisor notified the contractors that he is worried about the hammering effect of the pressure air pump. The pressure was nearly reaching the maximum pressure and going high/low. The supervisor decided to change the pump again before they continue to the next subsystem but they had no extra pumps available. Somebody called another subcontractor, who promised to bring a pump. When needed pressure level was reached, the supervisor told the workers to keep the level until the QC inspector verifies the results of the test. Injecting the water had taken so long that the QC inspector had left for the day. The on-call inspector was on site and promised to come after they called him. The work order contained two consequential independent verifications: a QC inspection and an authority inspection. The same person (the on-call inspector) did both inspections. He explained that he works for the power company's QC, as well as for an independent testing company. |
| The observed adjustment done by the maintenance | When the maintenance personnel identified that the first pump was broken, they replaced it with another one, which was however difficult to use because of the hammering effect it produces. After this they contacted the subcontractor |

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| personnel | company and asked if they can borrow their pump. The problem with the verification of the test results was solved by contacting the on-call inspector by phone and asking him to verify the results of both tests. They also worked overtime to finalize the task. |
| Our evaluation of the observed adjustment | To get the work done, the maintenance organisation executed the planned assignment through two different adjustments, and actively coordinated the activities with other parties in this process. The maintenance personnel's orientation towards fulfilling the organisational core tasks was evident in stopping the work when they identified a problem, knowing others whose work task relate to theirs (they knew whom to call), involving different parties and collaborating with them. However, their unawareness of the conditions of the available pumps revealed they were not properly prepared for the task. The adjustments were done by the maintenance organisation in respect, or at least not in explicit violation, of any of the safety culture criteria.<br>The ways in which the problems were solved by the maintenance organisation can be considered appropriate for dealing with the situation since the adjustments contributed to the execution of the panned assignment through coordinating the activities and adjusting to the situational circumstances. |
| Alternative ways of adjusting to the situation | *Repair the broken pump* – This strategy would have required the identification of the problem and fixing it on the spot, or ordering spare parts. This strategy would have resulted in delaying the schedule though.<br>*Order a new pump to replace the broken pump* – This strategy would have required significant disruption of the annual outage planning and delaying the availability of the pump.<br>*Neglect the hammering effect of the second pump* – This might have resulted in wrong results from the pressure test and could have jeopardized the functioning of a safety significant system. |
| Recommendations for supporting work practices and adjustments | In the observed case the execution of the pressure test could have been improved by inspecting the condition of the tools beforehand and then when problems were detected by reporting problems of using the pump. These work practices would have supported the maintenance organisation in creating valuable collective knowledge for better preparing for the task. Also, measures should be taken to re-arrange and ensure the proper performance of the two required consequential independent verifications: contact the QC inspector and an authority inspector to inform them about the delay. |

| **EPISODE 2** | |
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| Description of the observed episode | A major overhaul and modification was scheduled to be carried out in a short timeframe during the outage. The increased work scope and higher workload required new working arrangements: extra workers were borrowed from other units and two shifts system was implemented. The daily shift briefed all involved and provided an update on the current situation. There was a balanced distribution of experienced and new technicians, and the experienced and new technicians work side-by-side. On the job training was done partly also through story telling. Tools and spare parts were prepared in advance. A test scheme was placed on the wall as a generic outline of the course of activities during dismantling and installing of the parts of the equipment. However, basically this |

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| | scheme was the only procedure they used. Also, a newcomer was not sure who his mentor was. |
| The observed adjustment done by the maintenance personnel | The organization solved the problem of the increased work scope and higher work load by *changing the work arrangement*: they allocated their human resources in a flexible manner, created a two-shift system, and redistributed the personnel in a balanced way by mixing newcomers with experienced workers, who have been working side-by-side but still, there was confusion among the newcomers over the mentorship and usage of procedures. |
| Our evaluation of the adjustment | To cope with the challenge of the increased work scope and higher work load, the organisation reacted to the unexpected situation by coordinating the work with other units; there were enough resources to do the work rearrangement, and to execute the planned assignment. The combination of experienced workers and newcomers was good from point of view of creating collective knowledge if working side-by-side was paired with clear roles (e.g. mentors). From the point of view of working practice demands, the organization adhered to the schedule and put efforts in getting the work done by adjusting to the changed circumstances through redirecting the available personnel to more urgent work scope, and involving different parties and collaborating with them. While adjusting to the situation, the organisation respected all of the safety culture criteria. The way the organization coped with the challenge of the higher workload and scope could be considered fairly good for dealing with the situation since the adjustment contributed to the achievement of the organisation core task. |
| Alternative ways of adjusting to the situation | *Keep the existing work arrangement* – A risky strategy as it would have led to increased levels work stress and impossibility to perform the task.<br>*Postpone the task* – This strategy would have required to significantly disrupt the annual outage planning and more importantly, it would have compromised the availability of a safety significant system. |
| Recommendations for supporting work practices and adjustments | In the observed case the coping with the higher workload and increased work scope could have been improved by early identification that such a major overhaul is likely to be scheduled in a short timeframe during the outage; reporting the specific way the changed work arrangement was organized, and reporting the challenges experienced, e.g. confusion among the newcomers and using one available procedure. These work practices would have supported the maintenance organisation in creating valuable collective knowledge for better preparing for the task. |

| **EPISODE 3** | |
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| Description of the observed episode | A newcomer was unsure how to use a computer programme, which was used in the testing of radiation measurement. The PC programme was used for 5 years already but the newcomer was alone for the first time in the field. He experienced frustration with using the computer programme. He asked assistance and guidance by phone from the maintenance person who was doing the very test in the control room: while the newcomer was in the field sending signals, the other person in the control room was checking if the signals come through. The maintenance person in the control room gave very adequate and |

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| | detailed instructions and the job was done. |
| The observed adjustment done by the maintenance personnel | Instead of using a procedure for using the programme, the maintenance person in the field solved the problem of using the computer programme correctly by contacting the maintenance person in the control room by phone. |
| Our evaluation of the observed adjustment | To make sure he is using the computer programme correctly, the maintenance worker in the field adjusted to the situation and managed to execute the planned assignment by coordinating with the maintenance colleague in the control room. He did this by putting effort in getting the work done, asking questions. The adjustment was done in respect to most of the safety culture criteria, except perhaps for the criteria “activities are organized in a manageable way”: although it is a common practice that they work in pairs, the maintenance person was sent alone in the field (a sign of insufficient resources) without instructions(a sign of unavailable/inadequate instructions ).<br>The way in which dealing with the issue of using the computer programme correctly was solved by the maintenance person can be considered satisfactory for dealing with the situation since the observed adjustments met the demands for executing planned assignments while coordinating activities with other parties. |
| Alternative ways of adjusting to the situation | *Ask for peer support in the field, not only by phone*; maybe there could have been a supervisor guiding him - This strategy would have required further available resources. |
| Recommendations for supporting work practices and adjustments | In the observed case solving the problem with the computer programme could have been improved by preparing for the task well in advance; working in pairs – the newcomer could have shadowed a more experience colleague, and enhancing the quality of the written instructions<br>These work practices would have supported the maintenance organisation in creating valuable collective knowledge for better preparing for the task. |

| **EPISODE 4** | |
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| Description of the observed episode | The task was part of the pressure test of a large tank. When the required pressure level was nearly reached, they found they are unable to keep the pressure. The maintenance staff concluded that there must be a leakage. It is a common practice first to check the tightness of the isolation valves, rather than to suspect that the vessel is leaking. They called the control room and asked them to check the isolation valves. Two field operators came. They were newcomers and did not know the system in detail. They were checking drawings of the system but were not sure where exactly all the valves were. They were actively walking through different sections in different floors, calling a more experienced field operator for instructions, and going back to the subcontractors to ask help. It took more than an hour to find and tighten the leaking valves, which resulted in delay in the schedule for the maintenance working group. |
| The observed adjustment done by the maintenance personnel | The maintenance personnel identified the problem with keeping the pressure, stopped the work and informed the control room. The two field operators solved the challenge of finding the right valves to be tightened by consulting a more experienced field operator, and asking the subcontractors for help while |

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| | in the field. |
| Our valuation of the adjustment | The maintenance personnel who identified that there is a problem with keeping the pressure did well when decided to stop the work and to contact the control room. To cope with the challenge of finding the leaking valves, the organization had to adjust by calling different parties for consultation (coordinating the activities) and eventually fall behind the schedule. While executing their assignment, the two field operators worked in pairs, were active and put effort in getting the work done, they knew others whose work task relate to theirs so they collaborated actively with other parties, they relied on a subject matter expert available on call, asked questions, identified relevant expertise needed to get the job done, and used multiple communication channel (face-to-face and phone). They adjusted to the situation by respecting the safety culture criteria, excluding the "activities are organized in a manageable way" as long as it took more than expected to identify and tighten the right leaking valves.<br>The way in which dealing with the problem of finding the leaking valves was solved by the maintenance organisation can be considered fairly good for dealing with the situation since the observed adjustments met the demands for executing planned assignments while coordinating activities with other parties and adjusting to the changed circumstances. |
| Alternative ways of adjusting to the situation | *Trial and error* (e.g. over tight/under tight wrong valves) – This strategy is very risky because it could jeopardize the operability of other systems and the overall safety of the plant.<br>*A newcomer work together with an experienced operator as a pair in the field* – This strategy could have been very successful and would have resulted in keeping the schedule. |
| Recommendations for supporting work practices and adjustments | In the observed case solving the problem with finding the right valves could have been improved by e.g. development of 3D drawings for mobile devices to be used in such situations; enhancing the quality of the existing written instructions, and combining newcomers with experienced people to work side-by-side<br>These work practices would have supported the maintenance organisation in creating valuable collective knowledge for better preparing for the task. |

| **EPISODE 5** | |
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| Description of the observed episode | Technicians are installing jacking oil piping in the turbine bearings. A set of pipes (originally installed in the bearing a year ago) does not match the lead-ins. The technicians do trouble shooting by blowing into the pipes and sensing if the air comes out, thus figuring out if there is a pipe without a connection. They concluded that one of the pipes is in a wrong position. This finding indicated a year old latent error in the piping. The supervisor said he is rather sure that the piping was done according to the drawings the last time, so he assumed there was an error in the drawings rather than in the installation. He did not have the drawings with him. |
| The observed adjustment done by the maintenance | The technicians identified the problem with the mismatch between jacking oil piping and the lead-ins, and informed the supervisor. Faced with this unexpected finding, the maintenance team concluded that the work was done |

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| personnel | correctly last time, and there must be an error in the drawings. |
| Our evaluation of the adjustment | To get the work done, the maintenance organisation adjusted to the situational circumstances by being active and putting effort in the work, they paid attention to anything unusual, in case of unexpected finding; they stopped and informed the supervisor. However, they did not seem to have clear idea how their work relates to the work of other groups. We found it problematic that the maintenance personnel did not check what is in the drawing – this could be indicative for insufficient understandings of the hazards and safety as a systemic phenomenon. The way the mismatch problem was solved can be considered satisfactory for dealing with the situation since the observed adjustment mainly focused on adjusting to the unexpected finding. |
| Alternative ways of adjusting to the situation | *Find the drawings and check them* – This strategy could have helped them to diagnose the reason for the mismatch and to continue working safely.<br>*Assume there is an error in the installation and start dismantling the system* – This strategy would have resulted in a delayed schedule, overwork, and potential jeopardizing the operability of other systems.<br>*Contact the designers, who made the drawing and the maintenance team that installed the piping last year to identify what is the reason for the mismatch and what is the right way to proceed* – This strategy could have been time consuming, and could have resulted in a delayed schedule.<br>*Check the installation reports and the drawings from the last year; check how the finding refers to the modification of the bearings* – This strategy could have required some time but could have been informative on the right way to proceed. |
| Recommendations for supporting work practices and adjustments | In the observed case solving the problem with the mismatch between piping and drawings could have been improved by, e.g. having the drawings related to the installation of the piping in the field; improved coordination between designers and maintenance units, and utilizing past experience, screening the reports of the previous installation and if some problems were identified one year ago. These work practices would have supported the maintenance organisation in creating valuable collective knowledge for better preparing for the task. |

The episodes reveal that unexpected, underspecified situations, such as e.g. unknown condition of the equipment, faulty/unavailable instructions, lack of coordination with other groups, changes in workforce, varied condition of the tools, certain tasks need to be done before the work can begin, etc. are quite typical for the maintenance organization. According to the interviewees, such situations are so typical that they often did not pay too much attention to them, or do not explicitly reflect upon the decisions they have made. For most of these underspecified situations we observed that there was no specific instruction on how to proceed:

> *"For the repairing work we don't have instructions – many different parts can get broken, we cannot make instructions for each and every piece"*

Work practices and the adjustments in maintenance are strongly influenced by the experience and professionalism of the maintenance personnel. Experience and professionalism are considered fundamental to compensate dysfunction of the maintenance organization and gaps in procedures and instructions.

*"5-10 times a year we have an unexpected situation in which we need to consult other more superior or experienced guys."*

"*We never know if it is going to be easy or difficult. But we have good guys who can do it quite quickly".*

*"If it is a repair job: I take the best guys with me, we discuss what we have to do and then I prepare the work papers".*

When an adjustment results in creating problems e.g. unavailability of a certain technical system, this could a posteriori be considered a human error. If, however, there are not any noticeable consequences related to the operability of a technical system, then the same adjustment is considered part of normal organisational practice. From safety management perspective this kind of a hindsight approach is not fruitful because it does not consider the complexity of maintenance activities and cannot be used for assessing work practices before the results of their execution becomes manifested.

In the vast majority of cases the implemented adjustments were successful and supported effective maintenance work. But sometimes it happens that this is not true. Even if adjustments are performed with good intentions, they could end up in jeopardising the safety and functionality of specific components or, in extreme cases, of the overall nuclear plant. The distinction between successful and unsuccessful adjustments is therefore the precondition for reducing dysfunctional adjustments and supporting the functional ones and ultimately developing resilient adaptive practices.

Following the Resilience Engineering perspective, we focused on understanding how maintenance people succeeded in making their adjustments. For example, there was a general agreement that good *coordination* is of high importance for successful performance of activities in maintenance organization, both in planned and in unexpected situations. The issue of coordination was commonly raised especially by senior maintenance staff, e.g. foremen, who bear responsibility of organizing the everyday work in the best possible way. For example meetings were reported as usually useful for coordinating activities:

*"Every morning we have meetings, malfunction reports, we look briefly and we discuss what we do."*

*"Coordination is quite stable."*

At the same time the way in which coordination is done in practice may have limitations which can create challenges for the execution of the work as one of the interviewees reported:

*"We have coordination but more on paper, there is not a good understanding."*

Related to the coordination is the challenge associated with the work permit system, which is also perceived as influencing maintenance activities. Work permit systems aim at keeping track of the on-going works at the plant and support maintenance organisations in respecting the logic and safe sequence of activities. They also indirectly contribute to coordinating activities between different maintenance groups (e.g. mechanics and electricians). In this respect the transparency of the work permit system is considered important by maintenance personnel to avoid potentially risky assumptions which may lead to errors or misunderstanding:

*“The work permit system is not transparent. We assume that if we have gotten our work permits it means that mechanics have completed their work.*

The observations and the interviews revealed that sometimes high work load and time pressure require work rearrangements in order to get the work done, but sometimes the high workload of maintenance supervisors can pose certain constraints for successful adjustments:

*“Time pressure is the biggest stress. But in the end we always have the time to do the job.”*

*“I have a thousand works under my responsibilities, I don’t have time always to check how the last job was done previous time, I don’t have time to read instructions; I just have to remember things”.”*

Relying on “collective memories” appears to be an approach used by maintenance personnel to improve their own performance as reported by a mechanical maintenance person:

*“If it is impossible to do […] I know how to make it next time. I will remember next time – we just rely that someone remembers about that.”*

However, the importance of creating collective knowledge for making successful adjustments at work was recognized by the interviewees, as well as its ignorance:

*“Creating collective knowledge is getting more and more important at our plant.”*

*“We are not doing this creating collective knowledge a lot.”*

This indicates that the need to systematically create collective knowledge in the maintenance organization is not yet fully recognized, and the proper organizational systems and structures to create preconditions for creating this knowledge are still underdeveloped.

## 2.3 Guidance on developing resilient work practices

Based on the findings of the MoReMO project, we suggest that resilient work practices can be developed in the maintenance organization by supporting organisational vigilance and attentiveness to unexpected situations, and elaborating means for coping with them in a flexible manner. Improved understanding on different coordination mechanisms could also be beneficial for building resilient adjustments. We propose that the ways of making successful adjustments in the maintenance organization can be turned into resilient work practices, which could create capability for effective and safe daily adjustments. Improving the resilience of work practices is a process, which consists of three generic steps, and requires regular reflection and development of organizational capability to continuously close the "loop" and return to the first step. Figure 5 illustrates the steps in this improvement process, which includes local identification of work practices and discussions (assessment) of their safety relevance. It could also be argued that practices are embodied in the individuals' bodily operations and collaborative behaviours, and distributed in the tools and technological environment. We state that organisations should become aware of and continuously reflect upon their own work practices, and get an insight on the consequences their practices have on safety.

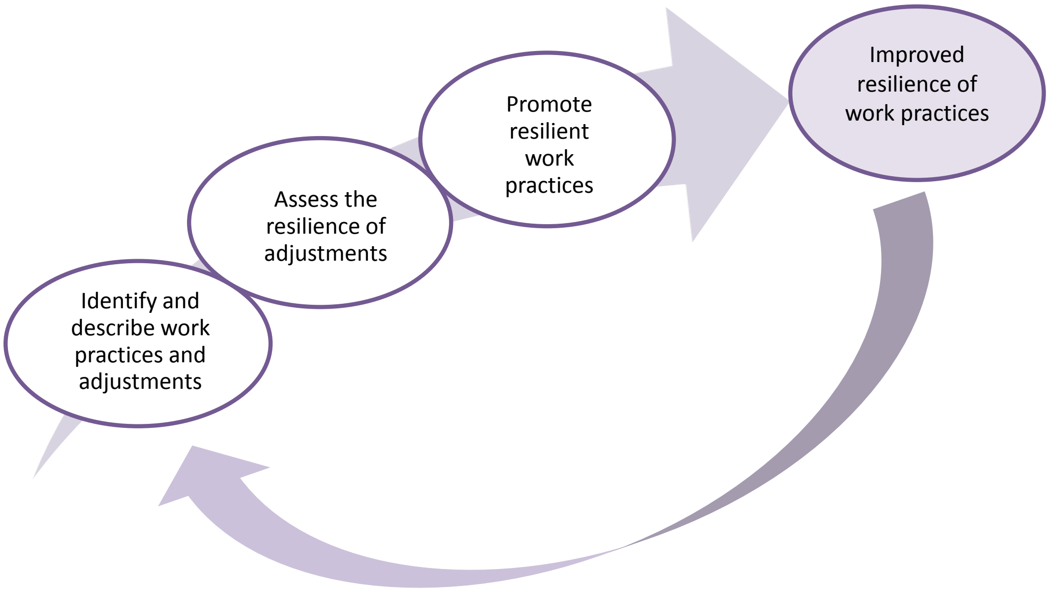


**Figure 5. The process of improving the resilience of work practices.**

On the one hand, the solutions for developing and supporting resilient work practices in maintenance organisations cannot be too complicated or time consuming, because maintenance personnel may need to rapidly respond to surprises and have little time to use tools for making ad-hoc decisions and adjustments. On the other hand, the solutions and tools cannot be too simple or rigid either, because they have to take into consideration the uncertainty and complexity of the maintenance work. Appropriate solutions are adjusted to the needs and context of a specific organisation and their meaning is understood and shared by the people in the organisation. In these situations maintenance organisations should have at disposal goal-oriented response framework rather than concrete and detailed action oriented protocols, which will soon fall short in supporting the work. In order to really be of practical use the solutions should aim at changing the perspective with which maintenance work is organised and in which maintenance organisations prepare for surprises.

Based on the results from the MoReMO project, we developed an evaluation tool (checklist; see Appendix A2), which aims at supporting the working group, especially if a major ad-hoc decision is required. First, the checklist could be used for helping the maintenance organisation to pay attention to the fact that they do carry out lots of adjustments without paying much attention to them. Second, when a situation which needs adjustment is recognised, the checklist could help in evaluating whether the decision would be problematic in a long turn. Thus the checklist could serve as a practical safety management tool for supporting resilience in maintenance and outages.

We suggest that promoting resilient work practices in maintenance and outage can be done for example through the following set of recommendations:

*Recommendations for improving the structure and organisation of the work in unexpected situations by ensuring that there are structural means and human resources for carrying out the work in the organisation:*

- Ensure the availability of slack resources during outage.
- Ensure the availability of a large storage facility for the spare parts, and competent spare parts suppliers.
- Allocate enough time for discussing the task at hand with the working groups well in advance.

*Recommendations for improving the coordination and collaboration between different parties in the network, including subcontractors, in unexpected situations:*

- Ensure close collaboration between the maintenance organisation and the warehouse management in order to facilitate the execution of the work practices and needed adjustments.
- Ensure clear distribution of responsibilities between different organisations operating at the plan.
- Exemplify clearly the interrelations between different systems through different visual means.
- Build close network with key experts and participate in building and maintaining the general know-how in the nuclear power domain other than just within your own organisation. You may need extra resources and expertise quickly in adjustment situations.
- Ensure good communication between the subcontractor's supervisor and the plant's foreman so that he/she openly informs about the delays, problems, ad-hoc decisions in work scopes where subcontractors have their own supervisor, and the workers mainly communicate with him/her.
- Acknowledge that subcontractors also face the generation change and be prepared to provide more supervision and assistance than before.

*Recommendations for improving safety management and leadership decision-making by recognizing the need to create conditions for personnel to be prepared to respond adequately in unexpected situations:*

• Allocate sufficient time for the foreman to ensure their availability in different challenges in the field to provide understanding of the big picture e.g. about the safety significance of the system and interconnections between different systems when adjustments are done.

• Provide enough time for the foremen for going through the feedback info written into the work order systems to see if there is something that needs to be taken into account the next time.

• Clarify how to deal with work scopes where the company doesn't have written work instructions available but the services are done by the manufacturer's old manuals. Define rules for handling identified errors in the manual or possible updates in the system.

• Clarify what all instructions should entail (e.g. potential hazards, typical errors, worst case scenarios etc.) that help in all circumstances.

• Identify the existing common unofficial good work practices in the field that are meant for error/quality management, and support them.

• Develop more explicit rules concerning situations where field workers (with their supervisors) can proceed by themselves in a case of an unexpected finding. Currently, there are partially implicit norms, e.g. "it depends on the safety class", "it depends if I have done this before and I know what to do", "if it is during a test it is ok to check if e.g. tightening a valve stops the leakage", "a broken component can be replaced if there is a spare part in the warehouse", etc. Experienced workers are given more autonomy than newcomers.

*Recommendations for supporting the ability of the organization to recognise the boundaries of safe performance and to develop constant vigilance and mindfulness:*

• Encourage workers in the maintenance organization to write down even seemingly small adjustments (e.g. in a feedback box) to ensure a relevant source of reference for the next time when there is a similar or related assignment. The feedback can also be analysed more generally to increase understanding of what is going on in the organisation and applied to another work scope.

• Develop procedures for coping with unexpected situations, and inform the working group supervisors about them - the higher the level more generic principles may be in the plant.

• Encourage reporting specific problems and challenges when using certain tools, including unusual sounds, smell, etc.

• Identify the existing common unofficial good work practices in the field that are meant for error/quality management, and support them.

*Recommendations for supporting the development of skills and knowledge of the personnel for dealing with the unexpected, including training and socialization of the newcomers:*

- Encourage workers in the maintenance organization to write down even seemingly small adjustments (e.g. in a feedback box) to ensure a relevant source of reference for the next time when there is a similar or related assignment. The feedback can also be analysed more generally to increase understanding of what is going on in the organisation and applied to another work scope.
- Arrange mock-up training to develop strategies for coping with the unexpected.
- Train maintenance personnel in predicting what kind of spare parts will be needed with respect to the planned tasks and possible unexpected situations.
- Learn from other industries about successful ways to cope with underspecified situations.
- Develop organizational capability to turn tacit knowledge of experience workers into explicit knowledge in a form that can be transferred and understandable also for newcomers.
- Use storytelling in informal discussions to make sense of dealing with the unexpected.
- Build organizational capacity (i.e. competence and shared decision guiding rules) for self-organisation in unexpected situations.
- Train both subcontractors and in-house maintenance personnel for making ad-hoc decisions and reacting to unexpected situations.

# 3 Study B: Handling performance trade-offs – the support of adaptive capacities

## 3.1 Background

Resilience engineering acknowledges that local adaptations and human performance variability are prerequisites for coping with unforeseen and challenging situations (e.g., Hollnagel, 2011). One approach used in making sense of adaptations and performance variability is the analysis of goal conflicts and trade-off decisions (Hollnagel, 2009a; Skjerve, 2009). For individuals, the prioritizations and decisions may not be conscious, , but resolved by habit, social norm or established practice (Hollnagel, 2009a p. 16). Thus, balancing safety goals against other types of goals may be conceived differently by the employees who make the trade-offs in real time, and their own and other's assessments done in hindsight during interviews and analyses of events. Study B was performed in two phases:

1. The first phase of the study investigated goal conflicts and Efficiency-Thoroughness Trade-Offs (ETTOs) in maintenance (also reported in Axelsson, Hildebrandt & Skjerve, 2011).
2. The second phase of the study investigated performance boundaries and adaptive capacities of field operators during outage.

To provide a conceptual basis for the study, two approaches were identified that could support the investigation of performance trade-offs The first is a model to identify trade-offs that bound human performance (Hoffman & Woods, 2011). The other is a simple goal conflict typology for application in high-risk industrial settings (Skjerve, 2009).

Hoffman and Woods (2011) have developed a model that aims to identify the fundamental trade-offs that bound human performance. The five trade-offs identified are:

1. Optimality-Resilience Trade-off: Increasing the scope of a routine (e.g. procedure) increases the opportunities for being surprised in novel and out-of-the ordinary situations. Optimizing over some demands leads to brittleness when encountering other demands. Thus, systems need to balance between implementation and use of routines, and the developing and maintain appropriate resources, including knowledge and expertise, for being able to adapt to surprising events.
2. Efficiency-Thoroughness Trade-off (ETTO): Systems need to balance between being efficient and being thorough in the planning and execution or their activities. For example, the scope of plans needs to be evaluated against restrictions in personnel coordination and inflexibility.
3. Acute-Chronic Trade-off: Chronic goals tend to get sacrificed to acute goals, which in turn leads systems to miss how and where they are brittle.
4. Specialist-Generalist Trade-off: Responsibility defines roles. Specialist roles increase the ability to handle specific kinds of cases, but challenge the ability to deal with cases that cut across roles. Generalist roles enable handling diverse situations, but less fluently for specific kinds of situations. Plant organizations have to balance between investing on and developing specialist and/or generalist roles and competences, for example reallocating tasks between field operators, maintenance groups and contractors.

5. Distributed-Concentrated Trade-off: Distributing activities between different roles can increase the range of effective action, but increasing the distribution of activities can constitute a challenge for keeping them coherent and synchronized. Concentrating activities in single roles can produce more immediate progress toward goals, but also reduces the range of effective action. The challenge is to balance micromanagement with delegation over echelons.

Based on the assumption that employees in nuclear power plants do not consciously make prioritizations which they suspect may reduce the safety level unacceptably, Skjerve (2009) has suggested a simple goal-conflict typology for distinguishing different types of initiatives that facilitate adequate prioritization of safety goals in work settings, as illustrated in Fig. 6. Skjerve (2009) suggested that goal conflicts in work settings could be defined as situations in which a (safety) goal is in conflict with one or more other desired goal(s), as judged by individual(s) in real time and/or as judged based on the safety standards of the organization. The goal conflict comprises two dimensions: The first dimension is called Team/individual perception. It refers to whether or not an employee/team in real-time perceives that a safety goal conflicts with other goals. The second dimension is called Trade-off criteria. It refers to whether or not the organization in question has dedicated procedures (trade-off criteria), which specify how safety goals should be prioritized in the given situation. For the sake of simplicity, it is assumed that these procedures are perceived to be adequate, by the operational staff.

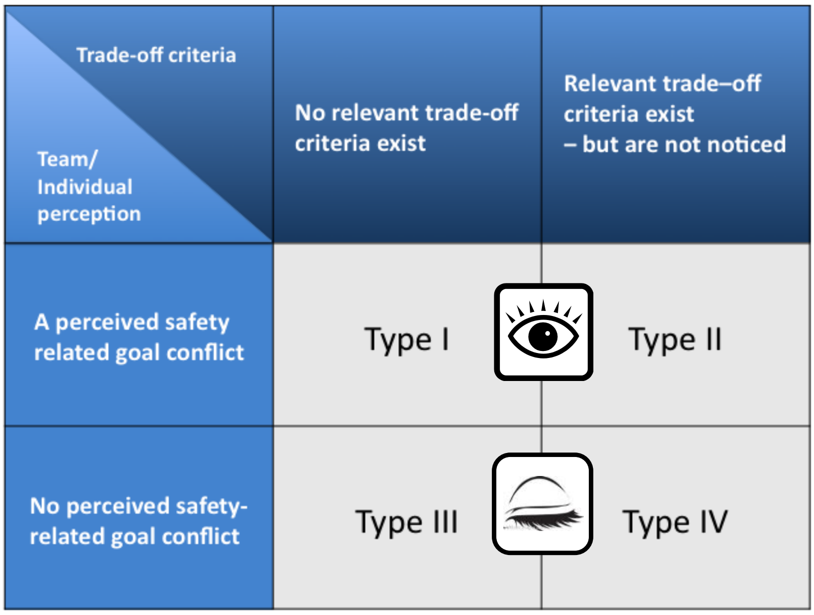


Figure 6. A simple goal conflict typology for high-risk industrial settings (Skjerve, 2009).

Type I goal-conflicts imply that an employee accurately (i.e., based on the standards of the organization) perceives that a safety goal conflicts with another goal, and accurately assesses that no specific trade-off criteria exists for how the situation should be handled. This type of situation may arise, e.g. when an individual is asked to achieve multiple conflicting goals simultaneously, e.g., to perform a highly complex task fast and safely at the same time in situations where the standards of the organization does not help him or her prioritize between these goals.

Type II goal-conflicts imply that an employee accurately perceives that a safety goal is in conflict with another type of goal, but is unaware that relevant trade-off criteria actually exist (if the individual is aware of the trade-off criteria, he or she will not experience a goal conflict, but simply prioritize the goals involved in accordance with the requirements in the standards).

Type III goal-conflicts imply that the employee does not perceive any goal conflict in a situation where a goal conflict actually does exist, as judged based on the standards of the organization, and where no trade-off criteria are available (or sought after). This type of situation essentially arises when an employee has not adequately considered the situation at hand from a safety perspective. A type III goal conflict may, e.g., arise when a situation is new or unexpected to the employee, or when the employee does not have sufficient time (given the means available) and/or competence to establish an adequate situation overview (situational awareness).

Type IV goal-conflicts refers to a similar situation as type III goal conflicts, in the sense that the employee does not experience any goal conflict, while carrying out his or her task. However, as judged based on the standards of the organization a goal conflict does exist – as well as standards for how to address it.

This goal conflict typology may serve as basis for distinguishing different types of initiatives for facilitating adequate prioritization of safety goals in work settings. Goal conflicts of type I and II point to the need for making the standards of the organization readily available to the employees. Goal conflict type III and IV point to the need for supporting the employees in obtaining an accurate understanding the risks associated with the situation at hand. It should be stressed that goal conflicts in practice may also arise between different type of safety goals.

The model of trade-offs and the goal conflict typology defines criteria for assessing working practices. We here present how these reference frameworks were applied: (i) Goal conflicts and trade-offs in maintenance, and (ii) Performance boundaries and adaptive capacities of field operators during outage.

## 3.2 Goal conflicts and Efficiency-Thoroughness Trade-Offs (ETTOs) in maintenance

Based on the literature analysis and an elaboration of the plant needs, we conducted an interview study to investigate the following topics:

- whether maintenance staff experience ETTOs in their work
- what kind of ETTOs they experience
- the sources of these ETTOs
- what kind of goal conflicts the maintenance staff experience
- why many ETTOs are resolved in a positive way

Eight maintenance staff at one of the case plants were interviewed specifically on the goal conflict point of view. The interviews focused on how they recognize safety goals, how they handle goal conflicts, and what supports positive work practices. The participants associated safety goals with the safety-relevant equipment they handled and performing the work in a professional manner, i.e. in accordance with norms of the group, the standards or their training, as well as application of human performance tools (e.g., pre-job briefings, stop-think-act-review). For planned work, the procedures support employees in performing the job safely.

In troubleshooting situations no procedures may be available and they rely on the team's experience to solve the problems. Regarding personal safety, the interviewees mentioned incidents that could have been avoided if the precautions in the procedures were applied. They attributed the failure to follow the precautions to complacency and misperception of the risk involved.

To investigate possible efficiency-thoroughness trade-offs, we tried to identify other goals that might be in conflict with safety goals. All respondents agreed that they experience high workload and periods of time pressure. One respondent mentioned an example where a contractor did not perform the job according to standards because of perceived time pressure. However, the respondent believed this to be an excuse for not performing the work thoroughly, and that the underlying reason was complacency. Another respondent brought attention to administrative routines that delay the work progress without benefits in safety or thoroughness of the task. Overall, the respondents stated that time pressure does not affect the quality of their work, referring to the policy of "you have as much time as it takes". None of the respondents indicated that budget or financial goals were an important constraint of their work. According to the interviewees, successful performance of work is related to individual characteristics such as the level of experience, perceived emphasis of safety and a questioning attitude; and team behaviour, such as cross-functional communication, mutual support and a positive team spirit. Obstacles to successful performance could be security routines requiring extensive foresight in planning, administrative burdens, ineffective coordination and individual priority issues.

The interviews did not provide strong examples of safety relevant trade-offs. As suggested in the literature (Hollnagel, 2009a, p. 16), ETTOs are often not conscious decisions, but resolved by habit, social norm or established practice. However, this resolution of goal conflicts may not be optimal, as shown by some respondents' remarks that procedures can be a hindrance and may not fit the situation well, thus providing limited improvement to the work performance. In such situations, teamwork was highlighted as an important cornerstone of safe work. Thus, future studies may look into ETTOs at the team and organizational level. In addition to obtaining a better understanding of how ETTOs can be managed in maintenance work, efforts should be directed towards developing new solutions that support both thoroughness and efficiency, reducing the need to make trade-off decisions. Fig. 7 shows different states in the efficiency-thoroughness space illustrating efforts to improve thoroughness and/or efficiency in maintenance work.

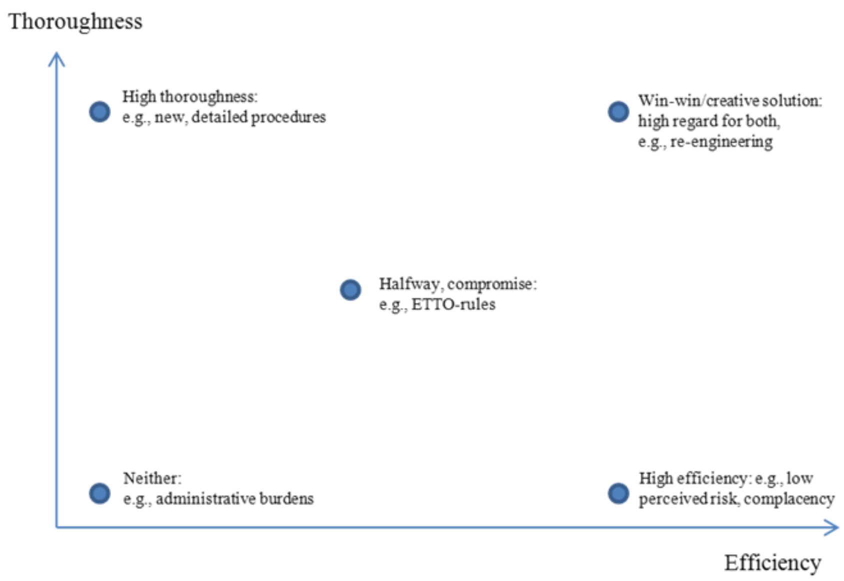


**Figure 7. The efficiency-thoroughness space showing different approaches to goal conflicts.**

## 3.3 Performance boundaries and adaptive capacities of field operators during outage

Only a few instances of ETTOs were reported in the interview study of maintenance staff. However, it succeeded in identifying a range of factors that may contribute to promote safe performance and adequate prioritization of safety goals. ETTO decisions seem to be made in team settings and may be difficult to recall during individual interviews. Thus, the second phase of the study was aimed at investigating a broader range of performance boundaries among field operators through group interviews and field observations. As in the first phase of the study, we looked at positive ways of handling these boundaries and supporting the adaptive capacities of the workers. Adaptability is seen as fundamental to cope with short term and long term changes in resource-constrained and complex environments (Woods, 2009). To develop new strategies, reorganize the work and mobilize additional resources are essential resilient mechanisms when a system reaches its margin of manoeuvre.

We developed a semi-structured interview guide (see Appendix B1) addressing the following topics:

- Identification of core tasks to better understand possible trade-offs and performance boundaries
- Chronic pressures, i.e., experienced demands, constraints and how the field operators perceive their margin of manoeuvre.
- Sudden pressures, i.e., situations where the field operators have been working close to or outside their margin of manoeuvre
- Measures to avoid approaching their margin of manoeuvre and support their adaptive capacities

We interviewed two groups of field operators from a Nordic NPP: four operators in the first group, six operators in the second. The semi-structured interviews were recorded, transcribed and translated to English.

We also conducted field observations during the outage at one of the Nordic case plants. We followed field operators when they performed tasks in the turbine systems during three days of outage. The field operators were video recorded during work performance.

The findings from the interviews and the outage observations are summarised and integrated in the following sections.

### 3.3.1 Field operators’ core tasks

After presenting the purpose of the study, the interviewees were asked to write down their core or main tasks as field operators. They were instructed to individually write each task on a small card and prioritize the importance of the tasks by numbering the cards. For each task, they were then asked to indicate which roles they needed to coordinate with to perform the task (green cards), the tools applied (blue cards) and documents related to the tasks (yellow cards). Fig. 8 below shows the main tasks of field operators, related documents, tools and involved staff reported by one of the interviewees.


**Figure 8. An example of field operators’ main tasks, the documents and tools applied, and the staff they cooperate with to perform the tasks.**

Fig. 9 below shows the distribution of responses on what the field operators perceived as their most important and highest prioritized tasks or functions.

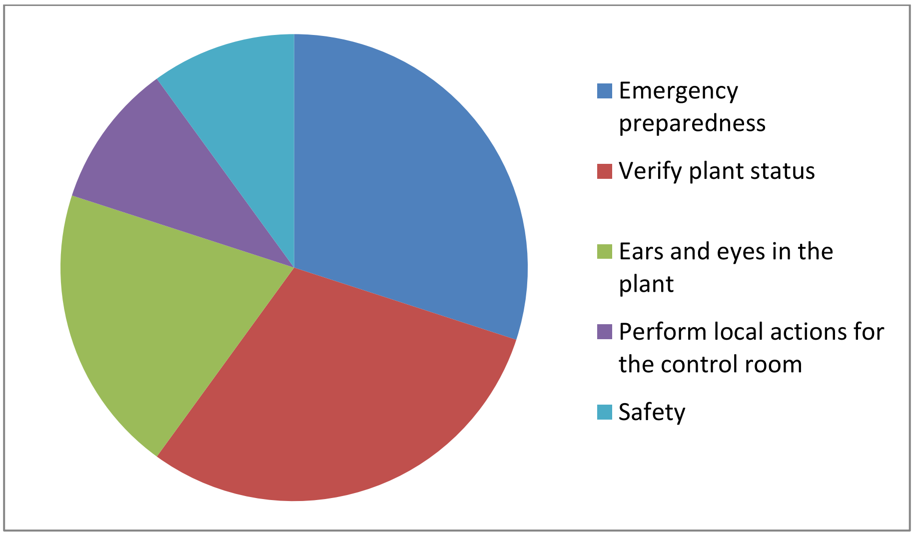


**Figure 9. Distribution of responses on what the field operators perceived as their most important and highest prioritized tasks or functions.**

Three operators reported that emergency preparedness is their most important task. To verify plant status was reported as the top priority task by three operators. Two operators perceived themselves as the control operators' ears and eyes in the plant, and one operator stated that performing local actions for the control room is the main task of field operators. Finally, one field operator reported safety as the highest prioritized task. All tasks listed in the figure are stated in the operators' original wording translated to English.

The number of main tasks reported by the interviewees varied from two to five tasks. In addition to the highest prioritized tasks, the operators mentioned object rounds, system tests, reporting deviations and failures, replacing components, adjusting flow and pressure, empty and clean tanks, small fixes and housekeeping.

For each task, the operators were asked to list the staff they're cooperating with, the tools and documents they need to achieve the task. The results are summarised in Table 3 below.

**Table 3. Main tasks reported by the field operators, staff involved in performing the tasks, the tools and documents needed.**

| Task | Other staff | Tools | Documents |
|---|---|---|---|
| Emergency preparedness | Reactor operator<br>Turbine operator<br>Shift supervisor | Process information system | Procedures<br>Emergency operating procedures<br>Drawings<br>Forms |
| Verify plant status | Control room operator | Handheld device<br>Phone<br>Keys<br>Vibration instrument<br>IR thermometer<br>Voltmeter<br>Adjustable spanner<br>Flash lamp | Pre-job briefing<br>Procedures<br>Flow diagram<br>ERF (experience exchange) |
| Ears and eyes in the | Control room | Handheld device | Pre-job briefing |

| | | | |
|---|---|---|---|
| plant | operator<br>Maintenance<br>Security centre | Phone<br>Flash lamp<br>Pen | Switching schedule<br>Procedure<br>Flow diagram |
| Perform local actions for the control room | Shift supervisor<br>Control room operator<br>Security centre | Phone<br>Vibration instrument<br>IR thermometer<br>Clip-on ammeter<br>Screwdriver<br>Pen<br>Flash lamp | Pre-job briefing<br>Procedures |
| Safety | Control room operators | Handheld device<br>Vibration instrument<br>IR thermometer<br>Keller pressure gauge | Pre-job briefing<br>Work order<br>Procedures<br>Drawings |

Most tasks involve cooperation and coordination with operators in the control room. In addition, the field operators may contact the security centre to get access to reactor buildings and certain restricted areas in the plant. For replacement and testing of components and systems, the field operators work together with various maintenance groups (mechanical, electrical, instrument), chemistry and radiation protection departments. Most tools and documents need to be brought from the control room. The handheld device is used for registering measurements during routine checks rounds in the plant and then connected to a docking station in the control room for storing the data.

**Figure 10. An example of the tools and instruments carried around when field operators perform local actions in the plant.**

### 3.3.2 Perceived pressures and performance boundaries

During outages, the field operators have a different task distribution and other tasks than during full power operation, such as shutting down the plant, close down components, drain and dry systems, and open and close valves. The perceived workload and time pressure is much higher during outages than during normal operation:

> *"It's much more to do during an outage. As night and day. Time pressure. All other work is put aside. Rounds are also given lower priority when you have time pressure and many systems to shut down. You just pass by… not the same chance to get help from operators or others either. Because, everyone is running out of time."*

> *"The time is a problem during outage. A job should have been completed when I get the paper in my hand."*

On the question of changes over time, the field operators replied that they have more tasks than previously, and more data to report, e.g., by use of a handheld device in addition to the handwritten reports. They also claimed that there are more viewpoints from outside on what the field operators should do, and that they get more requests from other departments.

The field operators complained about the restrictions on certain tasks, such as performing chemical tests, filling oil and unscrew equipment. The performance of these tasks depends on the availability of other departments:

> *"We're not allowed to unscrew things. It would be faster if I could do it myself. Instead of making a work request, get someone to come, tighten up a valve… We don't have the right competence. It's the same with filling oil on a pump. It should be made a work request. However, if we see that something is spurting, we don't remain watching it, but try to reduce the damage."*

Some field operators also expressed mistrust in other departments and groups, and that they're left with the physical work while the technical assessments and decisions are made by others:

> *"We perform tests on tanks that are given to the chemistry department. They decide whether we can transport the tank. (…) It feels like they don't think we can do anything. How difficult is it? They want to take care of the tank handling, but not do anything physically."*

> *"If we want to transport a tank… It takes a day to get the result from the chemistry group. To perform the test takes 30 min. If it's Friday, you cannot transport the tank until Monday. The plant closes at four Friday afternoon."*

> *"We're running with trash, paper recycling, laundry… We go out and perform tests for the chemistry group which they could perform themselves. Such meaningless tasks… The tasks have not disappeared. But it's so here. If it has been on paper once, it's not possible to take away. So you should ensure that not so many things get on paper."*

> *"We have a vibration instrument. That's used on a component during a monthly check round. And we have a vibration group. They're measuring four times a year.*

*Who are we measuring for? If the vibration group doesn't find it necessary to measure more than four times a year, and we're going twelve times a year. We're just logging the value. It's them who're looking at it."*

*"Who are we measuring for? Are we measuring for the sake of measurement itself, or is anyone interested in the result?"*

A similar issue on authority and feedback loops was raised when explaining the work clearance management system, with error detection notices remaining in the plant for years:

*"What never really has been working. If you make a work request and it's decided that nothing needs to be done, or that it's normal. It's no connection back. It could be stated "not done due to…" That you get a response on your work request, feedback."*

*"If I get a work request to follow up, but can't see any leakage… The pump is at full capacity. And the mechanics don't find anything. It might be as simple as the one writing the work request made a spelling error. Wrong turbine or wrong unit. Those who're receiving the notice cannot claim that it's not leaking. Then it's very easy to just contact the one who wrote the notice and ask "Where did you see a leakage?" That's a shortage of our system.*

The field operators also described what they experience as long-winded and troublesome routines even for performing simple tasks. For each task, they need to bring with them a number of documents such as work permits, procedures and drawings. The necessary equipment, tools and keys are stored in the control room, and they often need to pass several physical barriers, e.g., fences and scanners. They also mentioned that the introduction of a handheld device used during standardized check rounds resulted in double work as they maintain handwritten registration of data in addition to the digital logging.

The dependence on other departments and daytime scheduled work also affects workload during night shifts:

*"We don't have any shift working chemists, electricians, mechanics… so it should be adapted to daytime. So then, shutting down systems is often performed between 5 and 7 in the morning to be ready for daytime workers. That's not the time you're the smartest."*

*"It's much more to do during daytime when people are available. That's the way it should be. One should do as little as possible during nights, but still a lot of systems need to be shut down in the early morning. There, I think one interferes with the margin. It could be closed down during the early noon instead. Then, one's ready at 9."*

The coordination needs between the control room, the field operators and other departments were salient during our field observation of outage work. Both inexperienced and skilled field operators faced similar challenges. In one case, a highly experienced field operator was asked to perform a fire pump test. However, the test was postponed several times as the control room, the outage management and the maintenance departments discussed the premises for testing the pump and what type of procedure that should be used. When the field operator and the mechanical group started the test almost one day delayed, it turned out that the procedure for performing the test could not be followed as the presumptions for testing were not fulfilled. The field operator called the control room and the twin unit control room repeatedly to discuss the test. He also tried to make direct agreements with the maintenance workers on a new time for testing to improve the efficiency. The possible time windows for performing the test were noted on his hand.

The field operators emphasized pre-job briefing (PJB) as fundamental for improving safety and efficiency in their work. However, the time for PJB is limited during outages:

> *"The process [PJB] works well during normal operation. We don't have time during outage. Then, we sometimes fail to perform PJB. But if one is unsure of how to do things, anyone could demand a PJB. Then you get it. But it's not as self-evident during outage as during normal operation. But you shouldn't do anything you're unsure about."*

During the outage we also observed the importance of thorough briefings of the field operators by the control room operators before performing work. A recently licensed field operator was asked to perform a system shutdown and switching schedule in parallel. Due to a short briefing without explaining how these tasks could be combined, the field operator was unsure of the order of tasks and did not fully understand how these tasks were related and could be combined in an efficient and safe way.

The field operators also mentioned the communication with other departments as fundamental when performing pre job briefings:

> *"For example, if we're performing something together with a maintenance group, it's not necessarily our shift that takes part in the PJB. The PJB may have been done the day before. I think that's completely wrong…"*

Another frequent issue related to safe work practices was peer-checking and cooperation with other field operators. In general, there should always be two operators present when working on electrical systems. The operators mentioned examples of how this agreement is challenged and put aside in periods of high workload and limited resources available. They also questioned the control room monitoring of field operators working on their own for longer periods of time such as during night shifts:

> *"What I find strange. Maintenance workers always go two by two, while we're always running on our own. During the night everything can happen. No one is asking if you're away for two hours."*

> *"If I think of one of the latest nights. My colleague was out in the plant. Then, another task appeared. And one more. And she was away during the whole night shift. On her own… That's related to the control room management. So I asked the shift supervisor by six in the morning: "Has she been here eating? - Yes, I think so he replied. - I don't think so." And if you're a performance oriented type of person, you don't call to tell that you're eating. You just continue. That's dangerous, that's not good."*

> *"We changed a charging pump with a non-licensed field operator working alone in the auxiliary system. Think of what happened at the other unit… that an impulse line breaks. It's good to check the charging pump, the oil etc. If anything additional happens, then you're in trouble. Then you're outside the margin. It's a shortcoming to work alone in the plant."*

The field operators also claimed that the system knowledge is more distributed now. Previously, each shift had a special responsibility, kept an eye on certain systems which they knew in detail. Now, standardized rounds are introduced to ensure equal level of quality across systems, and the shifts have less specialized responsibilities:

> *"We had so-called large components follow-up. Each shift was responsible for certain systems and performed followed components in their systems. Then you knew these systems a little better. Now, the knowledge is spread… This was changed into system rounds. They are performed according to the shift schedule. So, now it's only me checking a system anymore. When this was introduced, there were no directions for how things should be performed. The quality varied. It ended with having a number of such rounds."*

When asked about situations where they have experienced to exceed the margin of safe operation, the field operators mentioned high workload during the last hours of night shifts, performing tasks on the switch gear on their own, and one concrete story from one of their process units:

> *"At the other unit, the fire in the containment. They should perform a pressure test, but did it in wrong operation mode. They wanted to save time."*

### 3.3.3 Modelling core tasks and performance boundaries of field operators

How can the perceived pressures and boundaries of performance be interpreted in light of the approaches on performance trade-offs and goal conflicts? Fig. 11 below shows an example of how the field operators' tasks and boundaries during outage can be illustrated by applying the OCT model (Reiman & Oedewald, 2007).

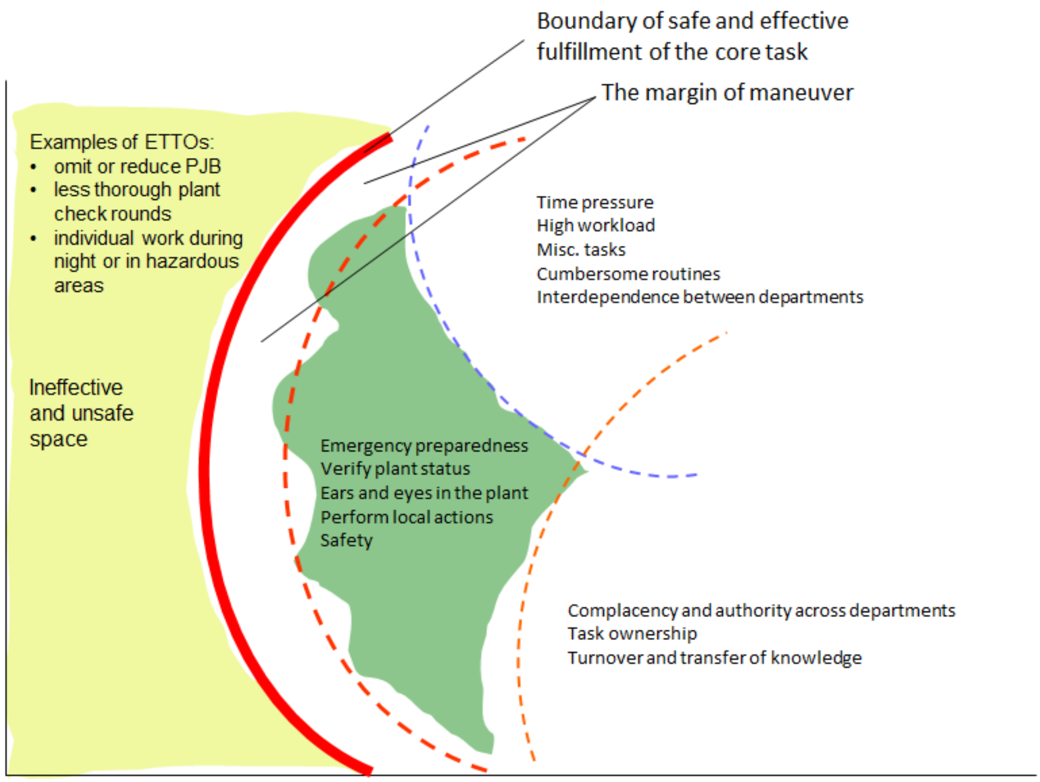


**Figure 11.** The green area covers the main (core) tasks of field operators. Their margin of manoeuvre for performing these tasks could be reduced due to high workload, time and resource constraints, and their trust in the competence of colleagues and other departments. When multiple goals cannot be met at the same time, the field operators experience ETTO situations such as reduced use of pre-job briefings and a high degree of individual work. The illustration is based on Reiman & Oedewald (2007), Rasmussen (1997), and Woods & Branlat (2010).

The field operators pointed to emergency preparedness and performance of local tasks and plant verification as their most important tasks. They perceive themselves as an extended part of the control room operation team. At the same time, their tasks and work are tightly coupled to other departments. A number of tests and checks are performed on request from other departments. Other tasks depend on tests or verifications performed by certain groups, such as measurements on tanks before transport. Several tasks during outage are also performed jointly between field operators and maintenance workers.

Among the constraints, or chronic pressures, that potentially draw attention away from the main tasks and reduce the margin of manoeuvre, the field operators emphasized cumbersome routines including handling documents, double reporting, carrying tools and equipment from the control room, passing physical barriers and fences. They also perceive a number of tasks as unnecessary or meaningless, as they may not be involved in technical decisions or get feedback on tests and checks performed on behalf of other departments. This may in turn affect their motivation and thoroughness in performing certain tasks. The questioning of work distribution across departments and authorities to perform tasks may indicate that field operators do not perceive goals conflicts in situations where a goal conflict actually exist, i.e., a Type III goal conflict (Skjerve, 2009).

The demands for communication and coordination with other departments were repeatedly brought up both in the interviews and during the field observations of outage work. These illustrate possible performance trade-offs between specialist and generalist roles, distributing and concentrating activities across roles (Hoffman & Woods, 2011). The high interdependence between different groups was expressed through the number of phone calls to update each other on the current state, progression of work and agree on the time schedule for upcoming and future activities. The interviews also pointed to dilemmas related to communication that could be interpreted as efficiency-thoroughness trade-off (ETTO) decisions during outages. While emphasizing pre-job briefings as a valuable tool for improving safety and efficiency of work, such briefings seem to be reduced or omitted due to time constraints during outage. The pre-job briefings could also be organized without the involved field operators to save time.

The extent of individual work among field operators in the plant and less follow-up from the control room could also be seen as ETTOs managed by the control room during outages. As a consequence, the field operators may refuse to call the control room when they get stuck, and rather contact other field operators to get advice. One interviewee interpreted this as an indication of reduced trust in the competence of the control room operators due to turnover and fewer years of experience. The time pressure may also influence the performance of routine tasks by the field operators as they give lower priority to and reduce the thoroughness on plant rounds during outage.

### 3.3.4 Measures to avoid approaching the margin of manoeuvre and support the adaptive capacities of field operators during outage

The study also aimed at identifying how field operators manage performance boundaries and avoid approaching their margin of manoeuvre: How do field operators mobilize resources when getting stuck, and how could their adaptive capacities be expanded? To avoid exceeding the margin, the field operators mentioned being early with known tasks and routines, and perform regular tasks more often than required. They also emphasized the importance of planning and preparations:

> *"Before the last outage we went through everything in beforehand, what to do, and how."*

Pre-job briefings were frequently discussed during the group interviews. The field operators highlighted the importance of involving all workers that actually would take part in the practical performance of the tasks. They also emphasized the value of a thorough briefing by the shift manager or control room operator before the work starts, especially when new staff is involved.

Still, newcomers frequently experience problems and situations they cannot handle on their own. In such situations, a newly educated field operator reported:

> *"Then I contact the control room operator. Call, or walk up to the control room if I have time. Everybody is very motivated to share their experience. However, it might be difficult during outage. Twenty years ago, you had an experienced colleague by your side all the time. Today, you cannot expect the same support from the control room. Normally, the activities are followed in a very different way. It's not possible during outage. The demands are much higher."*

Thus, the field operators reported that they may call each other rather than contacting the control room when they're stuck or need support. One reason for this could be changes in the education and turnover. Previously, the expertise was in the control room. As the current control room operators are less experienced, the field operators may prefer to ask each other and possibly leave the control room out of the loop. The observations provided examples of how field operators ask their colleagues for assistance, also from the other plant if needed. One field operator working on the generator cooling system also compared the system layout with the corresponding system on the other turbine to double-check his work.

The interviews pointed to the value of working new and experienced field operators together. The transfer of knowledge from one operator to another can never be replaced by a procedure:

> *"A procedure cannot explain the spirit of work. If a procedure should describe how you should solve a problem… it could tell you exactly what to do, but to understand… that type of experience exchange is reduced as I can see."*
>
> *"If I think twenty years back. The big change is that now you may walk around as a newcomer. We never did so previously. When you went out to the electrical system you had been here for ten years and knew things in a totally different way. You looked at how to do things, a visual transfer. Now, you may stay there two people together and don't really know how things are working. That's a big difference in the way of learning."*

Thus, the availability of additional resources in demanding situations requires a flexible organization of operators across units and levels of experience. The field operators may also systematically train on strategies for monitoring their own capacities (be aware of their margin of maneuver to avoid surprises) and getting extra expertise quickly to handle novel and unforeseen conditions.

The field operators also called attention to the lack of feedback through the work clearance management system. When the response to a work request is that nothing needs to be done, they would like to verify that the work request was correct and if found correct, learn why the system or component condition was found acceptable. Currently, there is no routine to contact the proposer of the work request and discuss the condition.

Learning is identified as one of the essential abilities for a resilient system (Hollnagel, 2011). In an interview study on resilience in operator training, trainers emphasized communication as fundamental to support learning (Gustavsson et al., 2011). Thus, establishing routines and system functionality for providing feedback on work requests could be a significant contribution to improve learning abilities in the nuclear power plant organization. This could also reduce the number of error detection notices remaining in the plant. At worst, a high number of outdated notices could lead to complacency problems (over trust) if workers override a notice that actually states limitations of certain components or systems that need to be taken into account.

The demands for communication, i.e., the needs for sharing information and updating each other on the work progress, were salient during our outage observations. We observed numerous calls between the field operators, the control room, the work permit centre, the outage management and the maintenance departments. In many cases the field operators went out in the plant to perform a task, but waited 30-60 min until they could start the work or were informed that the work was postponed due to delays on other jobs. During the interviews, the field operators discussed the possible benefits of using an integrated handheld device to exchange information and improve communication between the field operators, the control room and other departments:

> *"It would be fantastic to have a phone for recording movies, or an iPad. To do everything with one instrument: call, record, check the process, forms, procedures, localization of valves, limit values."*

> *"If we had procedures, drawings, a picture of a valve you cannot find. Could see the context. It's invaluable to have electronic documentation, to be able to update procedures electronically."*

The exchange of information across departments and locations may be enhanced through an integrated handheld device for field operators that enable access to real time process information, status on current activities in the plant, making phone calls, sharing videos and pictures, digital procedures and documents, and illustrations to enhance the localization of systems and components. This points to a possible win-win solution of re-engineering the system as illustrated in the ETTO space (see Figure 7). Efficient exchange of information and enhanced communication between field operators, the control room and other departments could reduce the need for making trade-off decisions and improve the ability to respond to novel situations.

Altogether, the ability to make risk-informed and timely adaptations could be supported through a more flexible organization of operators, and a closer cooperation between other departments may be considered. In addition, an integrated handheld device may enhance the communication and cooperation within and across departments and localisations, reduce some of the cumbersome routines when performing the core tasks, and consequently the extent of goal conflicts and needs to make trade-off decisions.

# 4 Conclusion

The MoReMO project aimed at presenting concepts on how resilience can be operationalized and built in a safety critical and socio-technical context. Furthermore, the project also aimed at providing guidance for other organizations that strive to develop and improve their safety performance in a business driven industry. Throughout the two years of the MoReMO project we applied four different methods and approaches to identify and analyse resilient work practices and adjustments in maintenance and outage activities in the nuclear industry: Organisational Core Task (OCT) modelling, Functional Resonance Analysis Method (FRAM), Efficiency Thoroughness Trade-Off (ETTO) analysis, and cultural approach.

Study A highlighted that Resilience Engineering provided good foundations for grasping challenges in maintenance and outage activities which typically involve dealing with unexpected situations and performing underspecified work tasks. In the context of maintenance, rules and instructions do not always cover all possible circumstances, thus in order to perform their work, maintenance personnel have to adjust their performance often relying on professionalism, expert judgment and coordination. By applying the Organisational Core Task modelling and the cultural approach, we identified criteria for evaluating work practices and adjustments performed by maintenance organisations and their potential contribution to the overall resilience of the plant. We have applied those criteria for describing and evaluating five episodes observed during the case studies. The OCT model and the cultural perspective also allowed identifying the strategies which were applied to deal with unexpected situations and were used to suggest alternative strategies that maintenance organisations could apply for improving their responses in the face of unexpected challenges.

The advantages of the methods used in study A are that they take a broad perspective and include different aspects of the phenomenon, e.g. OCT-modelling include the temporal dimension in developing core task demands and their associated work practice demands in outage (before, during and after); the safety culture criteria provide a broad view by including not only attitudinal aspects but also paying attention to the role of knowledge and understanding and organizational systems and structures for creating good safety potential in the organization. A disadvantage is that the broad perspective could make more difficult the correct application of the methods because criteria could be applied quite vaguely.

The main assumption behind the study of efficiency-thoroughness trade-offs (ETTOs) and goal conflicts in maintenance was that the interviewees would experience ETTOs in their work. Since only a few instances of ETTOs were reported, the first phase of the study B did not succeed in answering the research questions. However, the study identified a range of factors that may contribute to promote safety performance at nuclear power plants – and thus performance, which implies that safety goals are adequately prioritized. The second phase of the study B expanded the scope to look at a broader range of performance boundaries among field operators during outage and how their adaptive capacities could be supported. Through group interviews and field observations, we identified performance boundaries and trade-offs related to cumbersome routines, high workload and limited availability of other personnel in the plant. To avoid approaching the margin of manoeuvre and support the adaptive capacities of field operators during outage, the study also provided ideas for improving the communication and collaboration among workers, as well as technology that could enhance the mobilization of additional resources and ensure adequate prioritization of safety goals.

The analysis of performance boundaries and trade-offs applied in study B is one approach to understand how normal work is adjusted to cope with unforeseen and challenging situations. The first phase of the study illustrated the challenges of studying such everyday decisions, often made unconsciously and in team settings. The second phase of the study, conducting group interviews and observations of field operators, were able to capture examples of performance trade-offs and perceived constraints. The concept “margin of manoeuvre” was introduced in the interviews, but the respondents had difficulties in applying this concept. Thus, the interviewees were encouraged to suggest ways of improving the current work practices and possible technological solutions that may support adaptability during outage.

Both studies A and B aimed at advancing the understanding on making risk-informed and timely ad-hoc decisions in maintenance work, which contribute to the overall resilience of the nuclear power plant through the improved ability to adjust and cope with unexpected and novel situations.

**Future research**

Even in the highly standardised and proceduralised industrial settings like the nuclear industry, adjustments and ad-hoc decisions take place frequently. According to the resilience engineering approach, variations in the performance of workers should not be totally eliminated since variability gives rise to flexibility and thus ability to cope with unexpected and novel situations, and it contributes to the fulfilment of the core task of maintenance organisations. In addition, to improve the quality and safety of maintenance and outage work in nuclear power plants requires to take into consideration that when safety controls are too rigid, smooth execution of the work becomes more complicated and the likelihood of ‘cutting corners behaviour’ may increase. Rules and procedures, as part of the human performance tools, should therefore be conceived so that they do not complicate the work too much and allow sufficient amount of flexibility in the performance and to be effective they may needed to be tailored to fit the local working culture. The development and use of human performance tools for improving maintenance activities, their pros and cons, and their potential impacts on supporting resilient work practices deserve to be studied and better understood.

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# Appendix A1

## Study A: Interview scheme

1. Could you briefly describe your typical tasks?
2. How would you define the core task of the maintenance organisation? What is it that they need to achieve, why are they needed?
3. How does maintenance differ in normal operations and during outage?
4. [*The researcher is showing the figure with the six core task demands of the maintenance organization performing outage*] Of the following tasks, which ones are the more important for accomplishing your maintenance tasks, and why?
   a) Prepare for the tasks
   b) Monitor the equipment condition and plant operability
   c) Execute planned assignments without jeopardizing the safety functions and future operability of the systems
   d) Coordinate
   e) Adjust
   f) Create collective knowledge
5. If you skip one of these can you still perform your core task successfully?
6. What kinds of requirements do you usually have to meet in your daily work?
7. What kinds of specific pressures do you experience on your daily work?
8. You named […] as the constraints and pressures: how do you take these into account, how do you prepare for these? How do you cope with these?
9. If you could change one thing to make your (and the shop-floor workers) daily job more effective and safer, what would it be? Can you explain us how it would improve your work and why?
10. To accomplish your (shop-floor level) tasks, do you rely on detailed procedures or do you take a more flexible approach to the work? How do you know if/when you can take more flexible approach in an e.g. unexpected situation? Can you give examples, e.g. how ad hoc changes in the time schedule contributed to unwanted outcome or to plant safety?

# Appendix A2

## Preliminary checklist tool for evaluating maintenance adjustments

Based on our evaluation framework, we developed a first version of a checklist tool which might be useful for the power plant organisations for self-assessment purposes, in order to manage the effects of sudden changes and to improve the resilience potential of the maintenance adjustments. First, the checklist could be used for identifying adjustments, e.g. to help the maintenance organisation to pay attention to the fact that they typically do carry out lots of adjustments. Second, when a situation which needs adjustment is identified and described, the checklist could help in evaluating whether the decision would be problematic for the resilience of the power plant in a long turn. Therefore, the checklist could serve as one practical safety management tool for supporting resilience in maintenance and outages.

In the tool adjustments are presented in the forms of *solutions suggested* by the maintenance organisation to solve the problem. The first step for the actual evaluation of the resilience of adjustments consists in comparing the suggested solution or the observed work practice with the core task demands identified in the Organisational Core Task model, then it needs to be compared to the more detailed list of work practice demands, and finally to the safety culture criteria. This comparison provides an indication about the potential scope and aim of the adjustment and its coherence with the ultimate scope of the maintenance work and safety culture criteria. We state that adjustments which are performed taking into consideration only one out of the six core task demands without at least keeping the rest of the demands in mind are potentially risky since they may jeopardise the nuclear safety of the plant. If the observed adjustment is estimated to meet one or more work practice demands it is possible to argue that it was performed to help the maintenance organisation in fulfilling its core task. The evaluation of the riskiness or resilience of the adjustments has to take into consideration how they are done, e.g. adjustment which does not explicitly violate any of the safety culture criteria should not be considered risky. The evaluation of the adjustment can be supported by the following Resilience evaluation tool for maintenance activities.

# Resilience evaluation tool for maintenance activities

| | | | | |
|---|---|---|---|---|
| Describe the problem | | | | |
| **We** suggest the following solution | | | | |
| With the suggested solution **we**: | Prepare for the tasks | ☐ | Coordinate the activities | ☐ |
| | Monitor the equipment condition and plant operability | ☐ | Adjust to unexpected situations | ☐ |
| | Execute the planned assignment | ☐ | Create collective knowledge | ☐ |
| In the performance of the suggested solution **we:** | Involve different parties in the preparations | ☐ | Identify the relevant expertise needed in the work | ☐ |
| | Utilize past experiences, screen documents, etc. | ☐ | Prepare for unexpected findings | ☐ |
| | Reserve slack resources | ☐ | Analyse and document the nuclear safety significance of the work tasks beforehand | ☐ |
| | Acquire tools, papers, spare parts etc. well beforehand | ☐ | Pay attention to anything unusual even outside your work scope (walk eyes open) | ☐ |
| | Report findings and reward people for reporting | ☐ | Ask questions | ☐ |
| | Utilize of maintenance history database (or similar ICT system) | ☐ | Participate to face to face forums where feedback can be given | ☐ |
| | Explain what you are doing and what is relevant in it, make sure other stakeholder know the risks | ☐ | Report progress and delays | ☐ |
| | Utilize the know-how of the shop floor personnel | ☐ | Use multiple communication channels: phone calls, meetings, informal channels | ☐ |
| | Evaluate the safety impacts of any change in your work process | ☐ | Prepare to respond to local work scope circumstances | ☐ |
| | Analyse whether the preventive maintenance programme of each system is valid based on the information gotten during the outage | ☐ | Analyse whether the maintenance instructions were sufficient and correct for the workers | ☐ |
| In the performance of the suggested solution **we**: | Genuinely value safety | ☐ | Understand how the solution may influence nuclear safety | ☐ |
| | Have understood associated risks and core tasks | ☐ | Are mindful in our practices | ☐ |
| | Take responsibility for the functioning of the organisation | ☐ | Organise work in a manageable way | ☐ |
| Whom should **we** communicate with? | | | | |
| Overall assessment of the suggested solution | *Should we proceed or not? What is important to take into account in doing it? Why?* | | | |

# Appendix A3

### Application of the FRAM modelling

The scope of the FRAM modelling was to identify and describe the functions necessary to perform the maintenance of the diesel engine generator at one of the case study organisations. A FRAM 'function' refers to the activities – or set of activities – that are required to produce a certain outcome. A function describes what people – individually or collectively –, organisation and technological system have to do in order to achieve a specific aim. (For a detailed description of the FRAM modelling and of its results see Oedewald et al., 2012). The FRAM method provided a structure for systematically model the FRAM functions (i.e. the required activities for accomplish a goal) in terms of what are the inputs, outputs, resources, preconditions, time and control aspects that characterise them. The description of the functions also provides understanding on how the different functions are coupled and how they depend on each other (for example, the resource of a function is the output of another one). The FRAM model of maintenance of the diesel engine generator illustrated how this maintenance activity is deeply interconnected with several other activities performed during the outage as well as before the outage is started (e.g. spare part management, procedures management, and outage planning and control).

In this respect the FRAM model could be used to support the reasoning of how small deviations and adjustments in the performance of one function can influence the overall performance of the maintenance task and how small deviations and adjustments can combine and result in unexpected problems.

In fact the FRAM model could be used as basis for evaluating resilient work practices taking into consideration the potential effects of variability of performance and its consequences on system safety. On the other hand, the FRAM requires a certain amount of effort in its application. First of all, it requires personnel with a thorough understanding of the method and of its premises (Hollnagel, 2004). It also requires effort and time for collecting the data, and for building the FRAM model, checking its consistency and completeness, and identifying the potential sources of performance variability. Finally it requires time and effort in conducting the safety analysis, in drawing conclusions on its results and in proposing ways to improve work practices and facilitate adjustments. In the MoReMO project we limited the application of the FRAM to identifying and describing FRAM functions and their dependencies. The evaluation of work practices and adjustments was done applying the cultural perspective and the OCT modelling technique.

# Appendix B1

## Study B: Interview guide – field operators during outage

**Present the MoReMO project / the margin of maneuver concept**

- Describe, assess and support resilient work practices in Nordic NPPs
- Margin of maneuver - analogy to flight dynamics (flying "at the edge")
- Easier to lose control when the margin is exhausted
- A large margin is a source of controllability and resilience.

**Core tasks**

*Write main tasks, related activities and documents on cards. Sort the cards according to the core task relevance.*

- Could you briefly describe your main (core) tasks as field operator? Why are you needed?
    - Normally and during outage
    - Documents needed
    - Tools used (including handheld device)
    - Other roles involved
- What other tasks do you perform?
    - E.g., paperwork
- What are the main differences between normal operation and outage for you as field operator?
- If/how the tasks have changed during the years of operation?

**Chronic pressures**

- Let's think of your working day: What demands/constraints/limitations do you experience as field operator, what are your margin of maneuver? (e.g., knowledge, time, resources, physical hinders, administration)
    - What promotes safe and effective achievement of your main task?
    - What hinders (or may hinder) the execution of your main task? (e.g., unnecessary workload)
    - If/how the demands/constraints/limitations have changed during the years of operation?

**Sudden pressures**

- Can you describe situations where you have been working "at the edge"? (Or do you know examples of work "at the edge"?)
    - How did you recognize – what actions did you take?
    - What could potentially have worsened the situation?
    - If/how the situation could have been solved in a more efficient and safe manner?
    - If/how the situation could have been avoided?

*Scenario:*

Imagine you are doing a round and identify a (small/large) leak from a valve. What is the first thing you do? What is your role in dealing with this issue? What kind of work processes, documents, communications, handovers etc. are needed.

**Measures to avoid approaching the margin, support adaptability**

- How do you know whether and when you're approaching your margin of maneuver?
    - How do you recognize (and admit) that you can't handle a problem with the assigned resources in time?
    - What actions do you take to get support/help in such situations?
        - Roles, documentation, tools, technology

- What do you do to avoid getting stuck and remain within your capacity limits?
- What means do you have to limit negative consequences, how do you use them?
- How do you contact the right people/groups (who) and how do you communicate your problem and agree on a solution (e.g. get permission to do something outside a procedure)
- Can you think of alternative ways that this could happen?
- In the long term, how can the margin of maneuver be expanded, adaptability supported?

| | |
|---|---|
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Abstract

The project Modelling Resilience for Maintenance and Outage (MoReMO) represents a two-year joint effort by VTT Technical Research Centre of Finland, Institute for Energy Technology (IFE, Norway) and Vattenfall (Sweden) to develop and test new approaches for safety management. The overall goal of the project was to present concepts on how resilience can be operationalized and built in a safety critical and socio-technical context. Furthermore, the project also aimed at providing guidance for other organizations that strive to develop and improve their safety performance in a business driven industry.

We have applied four approaches in different case studies: Organisational Core Task modelling (OCT), Functional Resonance Analysis Method (FRAM), Efficiency Thoroughness Trade-Off (ETTO) analysis, and Work Practice and Culture Characterisation. During 2011 and 2012 the MoReMO project team has collected data through field observations, interviews, workshops, and document analysis on the work practices and adjustments in maintenance and outage in Nordic NPPs. The project consisted of two sub-studies, one focused on identifying and assessing adjustments and supporting resilient work practices in maintenance activities, while the other focused on handling performance trade-offs in maintenance and outage, as follows:

A. Adjustments in maintenance work in Nordic nuclear power plants (VTT and Vattenfall)
B. Handling performance trade-offs - the support of adaptive capacities (IFE and Vattenfall)

The historical perspective of maintenance and outage management (Chapter 1.1) was provided by Vattenfall.

Together, the two sub-studies have provided valuable insights for understanding the rationale behind work practices and adjustments, their effects on resilience, promoting flexibility and balancing between flexibility and reliability.

Key words: Resilience engineering, adjustment, work practice, maintenance, outage, field operators, organizational core task, safety culture, trade-offs

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