Resilience in High Risk Work: Analysing Adaptive Performance

by

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ABSTRACT

In today’s complex socio-technical systems it is not possible to foresee and prepare for all future events. To cope with the intricacy and coupling between people, technical systems and the dynamic environment people are required to continuously adapt. To design resilient systems a deepened understanding of what supports and enables adaptive performance is needed. In this thesis two studies are presented that investigate how adaptive abilities can be identified and analysed in complex work settings across domains. The studies focus on understanding adaptive performance, what enables successful adaptation and how contextual factors affect the performance. The first study examines how a crisis command team adapts as they lose important functions of their team during a response operation. The second study presents a framework to analyse adaptive behaviour in everyday work where systems are working near the margins of safety. The examples that underlie the framework are based on findings from focus group discussion with representatives from different organisations, including health care, nuclear, transportation and emergency services. Main contributions of this thesis include the examination of adaptive performance and of how it can be analysed as a means to learn about and strengthen resilience. By using contextual analysis enablers of adaptive performance and its effects the overall system are identified. The analysis further demonstrates that resilience is not a system property but a result of situational circumstances and organisational structures. The framework supports practitioners and researchers in reporting findings, structuring cases and making sense of sharp-end adaptations. The analysis method can be used to better understand system adaptive capacities, monitor adaptive patterns and enhance current methods for safety management.

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1 Introduction

In complex socio-technical systems all events and outcomes cannot be anticipated. People continuously adapt their work to cope with the changing environment and unexpected events, sometimes having to make challenging decisions and work around difficulties. This work is often done in situations governed by ambiguity and uncertainty. Consider, for example, a crisis response team who just found out that important parts of the team are delayed several hours due to weather conditions, or a train conductor dealing with people trying to get on and off the train while it is in motion, or the crew on a ship squeezing into a tight port during rush hour just as the fog is arriving. High-risk situations such as these, where systems have to deviate from the intended plan are not unusual; on the contrary, they happen all the time. For the most part situations have been anticipated by the organisation and responses are prepared, but some are not. Most situations are successfully managed, but some are not.

The less successful outcomes are the ones we tend to hear about, especially when there are casualties and large material damage involved. Lessons learned from incidents and accident analyses have been very useful in increasing system safety and preventing similar future events. However, studying only situations where something has gone wrong limits the understanding of the system as this only represents a small sample of outcomes in everyday operations. When an event is viewed in hindsight, there is a tendency to focus on the outcome and point out what “should have been known” or what “should have been done”, without full comprehension of contributing and sometimes conflicting factors such as time, efficiency and organisational pressure (Dekker, 2002; Fischoff, 1975; Woods & Branlat, 2010). Most nurses, pilots, control room operators and fire fighters will probably admit that most work shifts are not impeccable, and most operations do not happen exactly in an “ideal” manner, that is, the way they are described in procedures
Barshi, 2009). Disruptions and changes happen all the time, for numerous reasons, keeping people busy adapting to meet the needs.

As unsuccessful adaptations more often get scrutinised, a common view of human performance is that people are hazardous; an unreliable system component contributing to most incidents and accidents (Dekker, 2004; Woods, Dekker, Cook, Johannesen, & Sarter, 2010). This view of humans as unreliable and unpredictable has led to remedies aimed at limiting human variability by, for instance, increasing automation and altering procedures. However, little attention is paid to the other side of human variability where humans play a determinant role in keeping systems safe and how this ability is affected by the systems’ changes (Dekker, 2004; Hollnagel, 2011a; Rasmussen, 1986; Reason, 2008; Woods et al., 2010).

Knowledge about what enables or disables abilities to successfully adapt is rarely addressed in accident and incident investigations today, providing a less-than-acceptable baseline for interpreting actions leading to unsuccessful outcomes. Many adaptive acts to manage daily risks are not part of organisations’ instructions or procedures. Often these acts are not acknowledged or documented and therefore available only implicitly by individuals and teams in the organisation. Learning from what is actually happening in everyday operation (compared to the way things “should” happen) is therefore a necessary step for understanding what may be a threat to and what creates safety.

### 1.1 Perspectives on complex systems

Looking back, the development of socio-technical systems has vastly grown over the past century. Computers have become an important part of our work and this development has revolutionised the way we do things and the way we communicate. Over the years, technology has become more sophisticated, increasingly efficient and has allowed a whole new set of system abilities. Due to the advancements, the number of variables, parameters and system components have increased, as have the interdependencies and coupling between them, making systems more complex (Perrow, 1984). A result of this is that system processes are increasingly difficult to control. Difficulties in interpreting and predicting system behaviour and, hence, provide the correct response, has created the view that human variability is “hazardous” and makes systems vulnerable (Hollnagel, 2004).

As discussed by Hollnagel (2011a) different attempts have been made to deal with control and safety issues created by complexity. One attempt is to train people (adapt humans to machines), although this is often costly and it is difficult to maintain an appropriate level of training in an evolving systems. Another strategy is to improve system design (adapt machines to humans). Designing systems to provide humans with accessible and critical information at the right time has been the focus for many years. A problem with this approach is that the design solutions are largely based on analysis of unwanted outcomes.
and done in hindsight, only identifying changes to eliminate previously made mistakes. A third solution to overcome the limitation of human performance has been to automate systems (replace humans by technology), which has led to a whole new set of problems such as the fact that most complex tasks are still left to the operator, but with less knowledge about the system (Bainbridge, 1983; Sarter, Woods, & Billings, 1997). However, none of the strategies have succeeded in eliminating accidents or overcoming the vulnerabilities created by complexity.

The perspective that it is possible to build failure-safe systems was challenged in the 1980s. A key player in this debate was Perrow and his book “Normal accidents” (Perrow, 1984). Perrow argued that accidents should be expected as a consequence of the rapidly developing complex systems with tight coupling. There does not have to be failures for accidents to occur; it may just be a consequence of “normal”, varied, performance. Hence, searching for failures to “fix” through better design and training may not be sufficient to ensure system safety.

At around the same time the field of Cognitive Systems Engineering (CSE) emerged, and the focus of this discipline is to understand how to “cope with complexity” (Hollnagel & Woods, 2005; Woods & Hollnagel, 2006). Rather than aiming to create failure-safe systems it is seen as important to understand how joint cognitive systems; that is, human and machines seen as a single unit, adapt and modify their behaviour to cope with the demands of a complex work environment. Human behaviour must therefore be studied in the context of where the work is performed.

Stemming from CSE is the field of resilience engineering, a field that has increased in popularity over the past decade. In resilience engineering traits that allow systems to sustain operation in the face of unplanned and unforeseen events are in focus (Hollnagel, 2009a). Resilience is seen as a system’s ability to “adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions” (Hollnagel, 2009, p 2). Failures are viewed as a lack of ability to successfully adapt and used as a starting point for further investigation. Abnormal situations such as accidents are seen as the outcome of normal operation processes. Thus, to understand failures it is essential to also understand the successes (Hollnagel, Woods, & Leveson, 2006).
1.2 Thesis objective

This thesis is set out to investigate adaptive performance in complex system from a resilience engineering perspective. Through analysis of situations where systems are forced to adapt to changes and disturbances, the studies aim to investigate factors affecting the systems' ability to successfully adapt. Examples of adaptive situations used in this work come from a variety of different domains, including crisis and emergency response, health care, nuclear power and transportation.

1.3 Papers included

Two papers are included in this thesis. The papers are based on individual studies using observations and focus group discussions as a means to gather context rich examples of adaptive performance.

**Paper I**


Paper I reports the findings from an analysis of a crisis management simulation where parts of the command team are missing due a weather disturbance and cancelled flights. The command team adapts by re-structuring the functions and roles. The adaptation leads to some participants having to take on roles outside of their field of competence. The aim of this study is to deepen the understanding of the processes taking place during improvised work. The case study provides an in-depth analysis of the information and communication flow of persons acting in improvised roles, including contextual factors influencing the task at hand.

**Paper II**


Paper II focuses on understanding how adaptive behaviour in complex socio-technical systems can be analysed. Based on analysis of situations where people have to adapt their performance a framework has been developed to analyse adaptive performance in an everyday work setting. The framework categories include analysis of the context in which the adaptations take place, enablers for successful adaptations and their effect on the overall system. The examples that underlie the framework are derived from nine focus groups with representatives working with safety related issues in different work domains, including health care, nuclear power, transportation and emergency services.
1.4 Main Contributions

The main contributions are:

*Analysis of everyday situations in high-risk work where people have to adapt their intended plan to cope with system demands.* This research contributes to previous literature in human factors by emphasising that there is a need for new perspectives in safety management. The analyses show that traditional safety tools, such as incident analysis and introducing new barriers, are not sufficient to understand and ensure system safety. The examples show how safety is created through practitioner's ability to successfully adapt to current demands. Main results or the analyses include the demonstration of how interaction of different factors create and enable successful adaptations and the importance of analysing adaptations reverberations.

*Development of a framework for analysing adaptive performance.* The framework is intended as a tool for researchers and practitioners to structure and analyse adaptive performance. The framework can be used to enhance current safety methods used in industry today by providing insights into essential enablers for successful adaptive performance that may not surface through traditional reporting mechanisms.

1.5 Other publications


Thesis overview

The introductory chapter has provided an overview of the background, focus and aim of the work presented in this thesis. In Chapter 2, Background, the theoretical background and perspectives that underlie the work are presented in more detail. Chapter 3, Method, provides some reflection on the methodological approaches used and an outline of the methods used for the two studies. Chapter 4, Results and Analysis, offers an overview of each study, including the objective and the main results and analysis. In Chapter 5, Discussion, the results are discussed and suggestions for future work are provided. Chapter 7, Conclusions, summarises the main findings of the studies.
2 Background

This chapter provides an overview of perspectives and theoretical models that underlie this research. First, a brief introduction to some of the limitations of traditional models is presented (Section 2.1). Second, an introduction to a systemic perspective (Section 2.2) and the field of resilience engineering (Section 2.3) is given.

2.1 Limitations of traditional models

Models and methods for understanding and analysing systems have grown increasingly complex over the past century (as have the target systems) providing many insights regarding efficiency and safety. Despite the advancement of safety management methods large-scale accidents still happen, recent examples including the nuclear accident at Fukushima in 2011 and flight 447 that crashed into the Atlantic Ocean in February 2009. Contributing factors in both these examples demonstrate the complexity of today’s systems, and the difficulties in foreseeing all potential risks of expected and unexpected situations. Such examples of exposed vulnerability in high-risk systems suggest that new perspectives may be necessary in future safety management. Limitations of traditional methods that have been of particular interest in the studies presented in this thesis are discussed below.

*Traditional models of safety management use cause-effect reasoning to interpret interconnected, dynamic systems.*

Applying a method to investigate an occurrence is, for obvious reasons, useful as it provides a common language and viewpoint. Having said this, it is also important to keep the disadvantages in sight; the perspective of the method will be the perspective on the occurrence of investigation. Any method applied inherently includes assumptions of what
causes an event, which in turn affects the suggested remedies, or as articulated by Lundberg, Rollenhagen, & Hollnagel (2009a), “what-you-look-for-is-what-you-find”.

Methods for accident analysis have changed throughout the years, as have the systems and accidents they aim to investigate. The first models were simple and linear such as Heinrich’s (1959) Domino Model, providing a cause-effect description of events leading to the accident (see e.g., Leveson, 2011; Lundberg et al., 2009a; Qureshi, 2007). Over time, technology has become more reliable and focus has shifted to humans, often labelling accident causes as “human error” (Woods et al., 2010). By the late 1950s epidemiological models, or complex linear models, started emerging (Hollnagel, 2002). In complex linear models accidents are viewed as diseases, affected by hosts, agents and environmental conditions (Lundberg et al., 2009). The big transformation from the simpler models is the acknowledgment that situational factors play a role in the advancement of accidents, including latent factors such as environmental conditions and organisational aspects. The aim of the analysis was no longer just to find and eliminate specific causes but to create defences and barriers. However, the models still represent a clear cause-effect perspective providing plausible “causes” to an occurrence but not necessarily describing the interactions leading up to them (Hollnagel, 2002).

In the past couple of decades there have been an increasing number of new models with a nuanced perspective for analysis of accidents of complex systems (Harms-Ringdahl, 2004; Leveson, 2011; Qureshi, 2007; Sklet, 2004). The systemic perspective focuses on understanding couplings and interactions between system parts. This will be further discussed in the next sections.

Safety efforts are focused on what goes wrong

Historically, defining safety has been done based on its opposite, that is, the lack of safety, or the so-called Safety I perspective (Hollnagel, 2012a; Reason, 2008). Hence, safety has been measured in reports of adverse events and investigations of incidents and accidents. This work has provided nuanced ways of describing system failures using in-depth analyses (e.g., Harms-Ringdahl, 2001; Sklet, 2004), often uncovering deviation and violations of operational processes and prescribed rules (Dekker, Cilliers, & Hofmeyr, 2011). However, this does not seem to be sufficient to ensure safety. Although methods with the aim of eliminating adverse events were sufficient for simpler, tractable systems, the complexity of today’s systems requires additional approaches. As complexity grows modelling and predicting system behaviour become increasingly difficult. Analysing only adverse events may bias the understanding for the system as it puts constraints on the number and type of situations in which in-depth studies are performed, as well as the type of system interactions which are identified and examined.
Further, abnormal situations stem from normal operation processes and to gain deeper understanding these need to be better understood, or as suggested by Hollnagel (2009a); success and failure are not two ends of a pole, but rather two sides of the same coin; we cannot understand failures without also understanding the successes. In a Safety-II perspective it is therefore suggested to also study that which goes right (Hollnagel, 2012a). This allows a widened perspective of the system's successes with a focus not on eliminating all adverse events, but also ensuring that a system "sustains required operations under both expected and unexpected events" (Hollnagel, 2012a, p 2). This perspective will be discussed further in the next sections.

_Interpretations of human actions are done in hindsight_

A problem with interpreting people's role in the analysis of adverse events is _hindsight bias_, which may distort the analysis (Dekker, 2002; Fischoff, 1975; Woods et al., 2010). Hindsight bias means that we simplify situations in order to identify causes for explaining their outcome, as may be done when using simple models to describe an event. Reconstructing the causes of an event based on the outcome is limiting as there is a selection process of "causes". The "cause" may be selected as it is viewed as a deviation from procedure or not managed according to what is expected by rules and regulations (Woods et al., 2010). “Work as imagined”, is what, according to textbook examples, work should look like if everyone follows procedures (Hollnagel, 2012a). The problem with using “work as imagined” as a way of interpreting events is that the analysis often stops when a deviation from “work as imagined” is identified, as this is seen as the cause of the outcome. Interpreting people’s actions in the light of what “should have happened” and what they “could have done” to avoid an incident allows an explanation, but may not provide a deeper understanding of the problem. Although an accident may be the result of organisational factors, design problems and procedural shortcomings all concurring in time, hindsight bias narrows the explanation causing potential loss of understanding for other underlying factors (Dekker, 2004; Lundberg et al., 2009; Woods et al., 2010).

**2.2 A systemic perspective**

Cognitive Systems Engineering (CSE) is devoted to the understanding of how complex human-technical systems maintain control in dynamic environments (Hollnagel & Woods, 2005). CSE is a systemic approach for analysing, evaluating and designing joint systems. The view of human and machine as a single unit for analysis, or a Joint Cognitive System (JCS), allows an integrated view of how humans and machines work together. Hence, it is more important to focus on describing the functioning of the entire JCS than to use basic input-output models based on physical separateness (Hollnagel & Woods, 2005).
2.2.1 Control

A cognitive system includes people and technology jointly working toward a goal (Hollnagel & Woods, 2005). A JCS refers to a collective of cognitive systems and artefacts (social and physical) working in a goal-directed behaviour in a specified organisation. The boundaries of the joint cognitive system are relative, and defined by their functions and the purpose of the analysis. Typically in the area of cognitive systems engineering, one or more persons (controllers) and one or more technical support systems are involved in a goal-directed control process, working together in a complex environment.

Central for the ability to control a process and adapt in an appropriate manner is sensemaking (Klein, Moon, & Hoffman, 2006). Sensemaking is the process of structuring the unknown, and can be described as the interaction of seeking information, ascribing meaning and action (Weick, Sutcliffe, & Obstfeld, 2005). Making sense of a situation is an on-going process which is constantly (and for the most part unconsciously) being revised as the world around changes. One way to describe how systems maintain control though sensemaking and action is in terms of a control loop (Figure 1). The model is the basis for analysing the dynamic process of joint systems control and for interpreting how people take action where the context determines the actions. The control loop demonstrates how we use the past to make sense of the present, take action and plan for the future. Receiving the right feedback is important to anticipate, monitor and respond to a situation. Similar models have previously been used in, for instance, the military domain, DOODA-loop (Brehmer, 2007) and builds on Neisser’s perceptual cycle (1976).

![Figure 1. Basic cyclical model of sensemaking and control (Hollnagel & Woods, 2005, p 20)](image)

Many factors play a role in the ability to make sense of, adapt and plan in order to stay in control. These can be described in terms of constraints on, for instance, the amount of knowledge available in a situation or how knowledge may be retrieved when needed (Hoffman & Woods, 2011; Simon, 1969). Dissecting the features that constitute sensemaking
is challenging as it is made up of many parts not always explicitly available, such as our personal history and culture and subtle cues in our environment. Other factors include expectations, presumptions, social organisation, communication and emotions (Weick et al., 2005).

### 2.2.2 Complexity

Complexity can be seen as the antagonist of control; as systems become increasingly complex, humans are unable to compute or foresee all the failures that might happen and control the process (Hollnagel, 2011a). Perrow (1984) uses two main system properties to describe complexity: coupling and interactions.

**Coupling** refers to system parts being directly or indirectly controlled. In a system with many tight couplings a failure in one part of the system will soon spread to other parts. This makes the system more difficult to monitor and control. **Interactions** refer to the visibility and tractability of the subsystems. Interactions may be linear or complex. With linear interactions there is an expected sequence of events, and events will have predictable effects further down the line (Hollnagel, 2004). Complex interactions, on the other hand, are not as transparent; components are interconnected, tightly spaced and in close proximity. Interactions, therefore, may have an unforeseen sequence of actions, and failures surfacing in several areas at the same time. Couplings and interactions affect each other; a system with tight couplings and linear interactions is more predictable than a system with loose couplings and complex interactions (Perrow, 1984).

One way to describe the control of complex systems is through the law of requisite variety, which states that “only variety can destroy variety” (Ashby, 1956). This means that the number of states of the controller (or the control mechanism) must be greater than or equal to the number of states in the system that is being controlled. Cognitive systems are open systems, meaning that the boundary to the environment of the system is permeable, causing changes in the environment to affect the behaviour of the system. This means that the numbers of possible states are effectively infinite and that the problem space changes over time (Flach, 2011). An infinite number of states implies that in order to stay in control flexible control system must be used which requires constant adaptation to fit the current needs and match the variation of the processes being controlled (Hollnagel & Woods, 2005).

### 2.2.3 Variability and System Margins

The terms "sharp end" and "blunt end" are often used to describe different functions of a system and how they relate to each other (Reason, 1997). The sharp end includes people who operate and interact in the production processes, for instance, doctors, nurses, pilots, air traffic controllers and control room operators. The blunt end includes people who manage the functions at the sharp end, such as managers, regulators, policy makers, and government. Decisions made at the management level of the organisation, “blunt end”,
affects the conditions at the “sharp end” of the organisation. However, sharp end – blunt end relations should be described and analysed in relative rather than absolute terms as every blunt “end” can be viewed as a sharp “end” in relation to its managerial superior function(s) (see, e.g., Hollnagel, 2004, 2009b).

At both the sharp and blunt end of an organisation trade-offs are made between factors such as economy, efficiency and safety. System adjustments based on such trade-offs create system variability on all levels simultaneously (Kontogiannis, 2009) and may, over time, change the work patterns of the system (Hollnagel, 2004). This is important as it allows systems to adjust to current demands and to evolve. The other side is that variability generates unpredictability. Over time, adaptations will affect the overall system and change the organisation, sometimes in a direction that can lead to accidents (Cook & Rasmussen, 2005; Kontogiannis, 2009). Rasmussen (1997) describes this migrating effect in terms of forces such as effort and cost which systematically push the systems toward the boundaries of what is acceptable to ensure safety. As depicted in Rasmussen’s (1997) model (Figure 2), once the work performance has reached (been pushed to) the boundary of acceptable performance the system finds itself within the error margin, where accidents are likely to occur.

![Figure 2. The Dynamic Safety Model (Rasmussen, 1997, p 190)](image)

Rasmussen’s figure should, however, only be seen as a metaphor as the changes in work performance and the migration toward the boundary of acceptable risk cannot be described in any linear model, as the relationships between the forces and situational conditions vary. Alternative models are therefore needed to understand adaptations affected by different forces. One of the big challenges is to identify how organisational processes affect...
Background

potentially hidden processes and may push systems toward unsafe boundaries (Kontogiannis, 2009).

To summarise, it is never one factor which leads to failures but a combination of complex interaction, tight couplings and trade-offs that shape system states. People adapt to the social and environmental factors to make the best out of current conditions (Flach, 2011). The variability generated from these control processes is the source of both successes and failures (Hollnagel, 2009a). The ability to monitor system changes is critical to ensure a system stays within its boundaries for safe performance and avoid future catastrophes. Hence, ensuring that systems can sustain safe operation requires continuous work.

2.3 Resilience

There has been a recent interest in the notion of resilience in a variety of fields, such as economics, ecology, political science, psychology, and safety management. Although the disciplines may seem far apart they all have some fundamental aspects and challenges in common. First of all, they all suffer from systems with intricate dependencies and interconnectivities within and between the systems and subsystems, making them vulnerable to unforeseen events and disasters. Also, they are all subjected to an abundance of factors and interests affecting them, ranging from profits and power to environmental issues and resources. The joint challenge is to understand what makes some systems or system parts break down, where others manage to sustain basic functioning, that is, what makes them resilient.

The resilience perspective suggests that systems and system parts cannot be understood and analysed in isolation from the bigger picture. There is an acceptance that human ability to foresee and prepare for all possible future events is limited, that surprises will come, and that errors will be made. The aim therefore is to ensure that systems are capable of adapting enough to withstand disruptions and sustain functioning.

System resilience is determined by its ability to absorb shocks and maintain functioning as well as its capacity to renew, re-organize and develop (Zolli & Healy, 2012). This differs from stability in that a system’s stability is measured by its ability to recover and return to its original state after a disturbance (Lundberg & Johansson, 2006). Also, resilience differs from robustness, which is typically achieved by “hardening” the system (Zolli & Healy, 2012). For instance, the structure of a building may be very robust as it can withstand outside pressure but once it falls, it will not bounce back or regain any function. Redundancy is another related word often correlated with resilient systems. However, highly redundant systems are costly, requiring backup resources which may make systems very inefficient. A resilient system does not necessarily have to be redundant, as long as it has the ability to adapt (Zolli & Healy, 2012).
The definition of resilience may vary from one system to another. For example, in crisis management it generally refers to the ability and speed to which critical systems can sustain operation and be restored following an event (Manyena, 2006) and in ecology, it signifies the system’s ability to avoid irreversible degrading (Zolli & Healy, 2012). However, key aspects common to all fields are abilities to sustain functioning and recover in the face of change.

### 2.3.1 Resilience engineering

The field of resilience engineering stems from cognitive system engineering. Resilience is viewed as “the intrinsic ability of a system to adjust its functioning prior to, during or following changes or disturbances, so that it can sustain required operation under both expected and unexpected conditions” (Hollnagel, 2011b, p 2). The central part of this definition is in the system’s ability to adjust its functioning, which differs from the ability to continue functioning through, for instance, redundant systems (Hollnagel, 2009a). System variability, fluctuations and unexpected events are seen as a natural part of system operation and should be expected.

A system’s resilience is, in this perspective, determined by its abilities to cope with events that are unexpected or that do not fit the preconceived plan. On the contrary to what is perhaps the most common way to talk about resilience, as something you “have”, resilience should be viewed as something a system does (Wears, 2011). This view suggests that a system does not acquire or hold on to resilience, but it is something that transpires in a particular situation. Hence, the ability to adapt functioning in one situation does not necessarily imply that the system has the ability to adapt given different situations.

Hollnagel (2009) describes four central abilities to characterise resilient systems; anticipating what may happen (what to expect), monitoring what is going on (what to look for), responding effectively when something happens (what to do) and learning from past experiences (knowing what has happened). This can also be viewed in terms of sensemaking abilities, that is, seeking information, ascribing meaning and action (Grøtan, Størseth, Rø, & Skjerve, 2008). The sensemaking perspective also highlights that abilities based on our history and knowledge repertoire may not fully available to our conscious evaluation (Grøtan et al., 2008).

Although models of resilience are still in an immature phase, there have been several attempts to capture the essence of the resilience perspective in complex adaptive systems, stemming from Holling’s (2001) ecological approach (adaptive cycle) to engineering approaches of ball and cup dynamics (Scheffer, Hosper, Meijer, & Moss, 1993), and physical laws such as the stress and strain model (Woods & Wreathall, 2008). In a comparison of four different models Woods, Schenk, & Allen, (2009) demonstrate that key concepts of resilience are recurring in the different models. For example, concepts of system stability and stress the system can withstand is critical as well as the reserves available. Other models using a systemic perspective include the Functional Resonance Accident Model (FRAM) (Hollnagel, 2012a) and Systems – Theoretic Accident Modelling and Processes (STAMP) (Leveson, 2011).
2.3.2 Adaptation

One of the laws that govern cognitive work is the law of adaptation (Woods & Hollnagel, 2006, p 171). The law addresses the core of what makes JCS resilient; its ability to adapt to variations and surprises. The assumption that work in complex systems cannot always be carried out as planned and has to be adapted to fit the situation makes adaptive performance a core part resilience. Human factors literature is replete with examples of sharp-end personnel “filling in the gaps”, by finding alternative solutions in order to complete tasks in an efficient and safe way, also named “work-arounds” or “kludges” (Cook, Render & Woods, 2000; Koopman & Hoffman, 2003; Nemeth et al., 2007; Woods & Dekker, 2000). A major contributing factor to the adaptations identified is the rapid evolution of system technology to increase efficiency, production and safety. Often, the introduction of new technology produces side-effects not foreseen by the designers. This may include unintended complexities that increase the practitioners’ workload (Cook et al., 2000; Cook & Woods, 1996; Woods, 1993; Woods & Dekker, 2000; Woods & Branlat, 2010).

Other studies of sharp-end practitioners coping with complexity in high-risk environments describe adaptations as representing strategies (Furniss, Back, Blandford, Hildebrant, & Broberg, 2011; Furniss, Back, & Blandford, 2011; Kontogiannis, 1999; Mumaw, Roth, Vicente, & Burns, 2000; Mumaw, Sarter, & Wickens, 2001; Patterson, Roth, Woods, Chow, & Gomes, 2004). Strategies include, for example, informal solutions to minimise loss of information during hand-offs and to compensate limitations in the existing human-machine interface (Mumaw et al., 2000; Patterson et al., 2004).

Hoffman & Woods (2011) describe system adaptations as shaped by a number of trade-offs that place boundary conditions for the systems, such as efficiency-thoroughness, acute-chronic and optimality-fragility. While trying to balance several, and sometimes, conflicting goals, norms and values in expected and unexpected situations, adaptations of decisions and workflow are made by people at all levels of the organisation (Furniss et al., 2011; Mumaw et al., 2000; Rasmussen, 1986). Values and goals set by the blunt end concerning effectiveness, efficiency, economy and safety, will affect how the sharp end adapt their work. It is important to note that balancing these issues is not performed based on complete information and unlimited time for interpretation, but on the currently available knowledge and resources (Simon, 1969; Woods et al., 2010).

2.3.3 Improvisation

Adaptations may be based on well-known procedures and trained responses. Some situations, however, requires novel responses. A nuanced way to analyse novel actions is through the notion of improvisation. Definitions of improvisation may vary, but a common trait is the temporal convergence, i.e., structuring and planning of an action takes place as it is being executed (Chelariu, 2002; Moorman & Miner, 1998). Improvisation may include a range of varying behaviours, from small deviations in intended course of action to spontaneous action based mainly on intuition (Crossan, 1998).
Mendonca, Beroggi, & Wallace (2001) suggest that improvisation consists of “reworking knowledge to produce a novel action in time to meet the requirements of a given situation”. This definition emphasizes the importance of previous training and experience, which all come together during improvisation. Although improvisation may appear as an ad-hoc activity it is affected by experience, training, team-work and real-time information (Cunha, 1999; Grøtan et al., 2008; Mendonca & Fiedrich, 2006; Vera & Crossan, 2005). This conclusion, together with the assumption that we are not able to bring all skills into our conscious awareness, implies that the ability to adapt in an improvised way requires careful attention and preparation.

### 2.4 Summary

As systems have grown increasingly large and complex the limitations of traditional models of safety have become increasingly apparent. Resilience engineering attempts to address several of these issues by focusing not only on situations with a negative outcome, but also on normal variations happening in the everyday work environment. To be resilient requires abilities to sustain normal operations when faced with disturbances, which in turn requires enough knowledge and resources to adapt the process to fit the circumstances. Successful adaptation is therefore at the very core of resilience, as a means to cope with regular system fluctuations or unexpected events. Results from previous studies suggest that alterations to plans and procedures are constantly made to cope with variations and events in dynamic and complex systems. However, although informally recognised by many, it is not commonly something which is identified or well understood in organisations, leaving a large gap of knowledge between “work as imagined” and “work as performed”. With a better understanding of the complexities and the trade-offs that govern the work environment we can work toward building more resilient systems.
3 Method

In this chapter an overview of methods used to study joint cognitive system is presented (Sections 3.1 and 3.2). This is followed by a description of the methods used in the individual studies (Section 3.3).

3.1 A Cognitive Systems Engineering approach

A CSE approach focuses on studying human and machines in the context in which they work. It is the effort of the joint system, the relations between system parts and the phenomena which emerge as a result of system interactions that are of main interest (Hollnagel & Woods, 2005). This focus allows the influence of factors such as situational and organisational demands and coordination of work processes to be part of the analysis (Woods & Hollnagel, 2006). Further, it permits identification of interactions and relationships between people, technology and the work setting.

3.1.1 Classes of research methods

Research methods to study joint systems at work vary depending on the aim of the research and the conditions necessary reach that aim. Woods & Hollnagel (2006) have identified classes of methods based on the type of setting in which the study is carried out: Natural history methods, Staged (simulated) task environment and Spartan lab experiment.

Natural history methods or naturalistic observations (Flach, 2000) include a variety of ethnographical approaches to collect observations made in situ, that is, in a field setting. The goal of the method is an increased understanding of the work environment or activities to be described using natural settings or cases, see for example (Koopman & Hoffman, 2003; Patterson, Woods, Cook, & Render, 2006). Often the analyst will focus on identifying patterns in the natural context, capturing the "naturally" occurring constraints in various situations. Experiment-in-the-field involves simulating a staged or scaled environment to capture features which are believed to be the critical in the situation. The ability to shape and control the situational conditions in the simulated world allows the observer to gain deeper insights into particular aspects of the work. Simulated task environment will be elaborated on in the following section. The third and final class described is a Spartan lab
experiment, which refers to methods used to pick out variables and test in experimenter-created situations.

### 3.1.2 Simulated task environments

Simulated task environments aim to simulate features of actual systems for people that engage in tasks. The kinds of aspects range from one to a few aspects of many systems to many aspects of one system. The ability to target specific aspects of interest is beneficial as the conditions of the experiment can be controlled by the experimenter. A challenging but critical issue when conducting such experiments is designing the problems faced in the scenarios. A deep understanding for the mapping between the target situation and the test situations is required and should allow the study to make the items of interest tangible, and hence, observable (Woods & Hollnagel, 2006). Highly "realistic" simulations include many of the constraints occurring in natural environments, enabling people's expertise in these environments to apply to the simulation or exercise. Simulated task environments moreover enable measurement of performance at many levels, consequence-free evaluation of naturally high-risk activities, and higher control of constraints in the environment than natural environments, although lower than in a laboratory setting (Flach, 2000).

Interpreting and analysing observation data from staged world experiments is focused on tracing the process for which the JCS responds to the challenges created in the simulation (Woods & Hollnagel, 2006). A process analysis can, for instance, be done as a description of performance on different levels of abstraction, from raw data, to context specific analysis, to a formal and subsequently a more conceptual level of description (for further elaboration see Hollnagel, Pedersen, & Rasmussen, 1981; Woods, 1993). Performance descriptions can then be described and contrasted to cases across scenarios, domains or artefacts, aiding the researcher to abstract patterns of performance (Woods & Hollnagel, 2006).

This type of analysis generates the discovery of the nature of work, and the phenomena which emerge as a result of system interactions. These phenomena may be impossible to foresee or detect when analysing the different parts separately, as has been demonstrated many times as automated systems and system interfaces fail to support people at work sufficiently (Bainbridge, 1983; Sarter, Woods, & Billings, 1997).

### 3.1.3 Patterns of activity

Identifying patterns of how systems work and adapt to the demands of the environment is central to understanding complex systems. This is done by comparing and contrasting strategies and people's behaviour across situations and settings and not getting stuck in the details (Woods & Hollnagel, 2006). An iterative work process is required. For example, observation, abstract, generative and participative are four basic activities that can be used iteratively for testing new ideas for technological possibilities (Woods & Hollnagel, 2006). The two first steps, observation and abstraction involve understanding patterns in of the JCS and the second two steps, generative and participative, involve testing and discovering new design solutions using prototypes as tools. The analyst should critically examine the authenticity of the derived examples, that is, investigate how
well the proposed theories actually match the actual work performed in the JCS. It is also important that the analyst is constantly prepared to revise theories and ideas as new situations arise. Through iterative work of observing and testing the approach attempts to produce solutions to improve performance in dynamic event-driven worlds (Nemeth, Cook, & Woods, 2004; Nemeth, 2012).

Using narratives, i.e., observed or told story cases, is a good means to understand actual work as it helps the identification of not only the work we perform, but the relationship to other goals, and to technology (see e.g., Cook & Rasmussen, 2005; Koopman & Hoffman, 2003; Patterson et al., 2006; Woods & Hollnagel, 2006). The core value is, again, in capturing general and recurring patterns of work. For example, strategies to deal with disturbances, the use of artefacts, communication and coordination. The focus of the stories is not on the human or the technology, but on their ability to work together as team-players to adapt and control the dynamics of the work environment (Klein, Woods, Bradshaw, Hoffman, & Feltovich, 2004).

3.2 Interviews and focus groups

Interviews are conducted for a variety of reasons and depending on the purpose of the study, different approaches can be used. Commonly referred to interview categories are: unstructured, structured and semi-structured (Patton, 1990). Unstructured interviews include open-ended questions, giving the respondent the opportunity to elaborate in any direction. Structured interviews include a set of fixed questions, often including alternative answers for the respondent to choose from. In semi-structured interviews the interviewer will prepare questions and guide the respondent to ensure the prepared topics are covered, but alternatives will not be given, allowing respondents to elaborate on the topics discussed (Patton, 1990).

Group interviews can vary in structure; from open discussions based on a theme to more structured questions (Patton, 1990). A commonly used approach in group interviews is the concept of focus groups. In focus groups people are brought together to participate in a discussion of an area of interest (Boddy, 2005, p. 251). This qualitative research technique is different from (or can be viewed as a subset of) group discussions. Although group discussions may include a variety of styles, focus groups tend to be less controlled by the moderator, allowing both broad and in-depth discussions (Boddy, 2005). In focus groups interactions between the participants are viewed as an essential part and participants are commonly chosen based on this criterion (Wibeck, 2000). For the researcher facilitating the focus group the aim is to create an open environment that allows participants to discuss, argue, agree or disagree about a particular topic (Boddy, 2005). Focus groups also differ from spontaneous group discussions occurring during, for instance, participatory observations, as the topic of discussion is selected by the researcher and performed with a moderator (Wibeck, 2000).

Looking back, focus group techniques have largely been developed for and widely used in market research (Morgan, 1997). However, today the method is being used increasingly in an
academic setting (Boddy, 2005; Wibeck, 2000). The method has been found suitable as a means to explore new research areas or examine well-known research questions from a new perspective (Morgan, 1997). Studies may either be centred around the content of the topic discussed or on the interactions of the participants (Morgan, 1997).

Factors to consider when conducting interviews and focus groups may vary depending on the objectives of the study. General guidelines for planning interviews include doing a background check of interpersonal factors and previous experiences, relationships between the participants (if group interviews are involved) and the environment in which the discussions are to take place (Wibeck, 2000). Further, the researcher should carefully consider the number of interviews necessary, the number of participants for each discussion and if homogeneous or heterogeneous persons should be used (Morgan, 1997).

### 3.3 The studies

In this section the methods applied in each of the studies are presented.

#### 3.3.1 Study 1 – Analysis of crisis response simulation

The Swedish Response Team (SRT) simulation was based on a real event: the 2007 California Wildfires. According to the scenario, around 20,000 Swedish citizens are in the affected area, and a large number of citizens are requesting assistance from the Swedish embassy. The SRT’s mission includes an assessment of needs in the area of operation, as well as support and assistance of the Swedish authorities and citizens in the area.

Focus of the data analysis of the simulation was based on information from a previous focus group study (Lundberg & Rankin, in press). The focus group discussions covered experiences from previous missions in the SRT. Results showed that taking on roles outside one’s field of competence during a mission is common and that this may have both positive and negative implications for the success of the mission. The scenario in the simulation was subsequently designed so that important functions of the command team were missing, forcing participants to take on roles outside their field of competence. Participants in the simulation were operational personnel acting in their professional functions and posts.

The analysis of the simulation involved a triangulation of data for a single case. Five observers were present during the simulation, all communication was recorded (phone conversations, e-mails, log-books), photos were taken, interactions were videotaped, and notes written by the participants were compiled. The simulation went on for 4 hours and was followed by a 1 hour after action review. During the after action review the participants were asked to reflect on their own and on their team’s performance.

All data was reviewed, and any information that could be related to people taking on tasks not normally part of their function or expertise was extracted. An in-depth analysis of the communication and information flow throughout the exercise was performed and
Method

Information was structured into eleven sub-episodes allowing a chain of events to emerge. A focus was on reconstructing the information flow embedded in the context, to allow a view of who had what information at what time. This was further visualised on a temporal scale to provide a view of available information at a given time.

For more information on how the simulation was designed and carried out, see Trnká (2009). For information on the study leading up to the simulation see (Lundberg & Rankin, in press) and section 4.1.2.

The author of this thesis did not partake in the focus group study leading up to the simulation, but performed an analysis on the data based on voice recordings. The design and preparation for the simulation was not done by the author who partook during the simulation as one of the observers. Compiling the data following the exercise and performing the episode analysis was led by the author, and supported by the other observers and exercise management personnel.

3.3.2 Study 2 – Framework development

Focus groups (see Section 3.2) were used as a means to bring people from different organisations and work environments together to discuss situations related to resilience and safety culture. An aim was to get practitioners involved in cross-disciplinary discussions on learning from “what goes right”. The study was exploratory with the objective of investigating commonalities between organisations and to identify the potential of using general models of resilience. Discussions were centred on work situations where human adaptations often are critical such as near the margins of safety.

Nine focus groups were conducted with a total of 32 participants. The participants all worked with safety-related issues as well as incident and accident investigation in safety-critical domains. The following organisations were represented (and number of participants): Patient Safety (13), Nuclear Safety (8), Occupational Safety (3), Air Traffic Control Safety (2), Maritime Safety (2), Emergency Services Safety (2), Railway Safety (1) and Road Safety (1).

Approximately 70 examples of situations where people work near the margins of safety were identified. In 17 of the examples adaptations to cope with the risk were identified. All focus group sessions were recorded and the audio files transcribed. The transcriptions were coded using iterative bottom-up and top-down approaches. The transcriptions were first divided into categories based on the main topics of the focus group discussions. The bottom-up analysis was then performed, allowing new categories and sub-categories to emerge from the data (Miles & Huberman, 1994). This analysis laid the basis for the framework.
This study is a continuation of a research project investigating the underlying theoretical models used in accident investigations in several organisations in Sweden (see Lundberg et al., 2009; Lundberg, Rollenhagen, Hollnagel & Rankin, in press). The author of this thesis led the design of the focus groups and analysis of data. As focus groups were performed in parallel the author was one of three moderators leading the focus group discussions. All tasks were supported by the co-authors of Paper II.
4 Results and Analysis

This chapter provides an introduction to the main results and analysis from the two studies. In Section 4.1 the results from the first study (Paper I) are presented and in Sections 4.2 and 4.3 the results from the second study (Paper II) are presented.

4.1 Role improvisation in crisis management

The first study is an analysis of a command team adapting to the loss of important functions. To cope with the disturbance several participants have to take on roles outside their field of competence.

4.1.1 Overview

The aim of this study is to deepen the understanding of the processes taking place during improvised work “as it happens”. Crisis situations are often characterised by ambiguous and unplanned for events and the need for improvised roles can therefore be of great importance to cope with the changing events in a crisis situation. By identifying factors that affect the team’s ability to adapt to a disturbance system opportunities and vulnerabilities are identified.

4.1.2 Preceding focus group study

A preceding focus group study was used as a basis for scenario and study design of the simulation. The main results from the focus groups related to flexible roles are presented below. For a more elaborate discussion see Lundberg & Rankin (in press).

The focus group participants were SRT command team members and the topic of discussion was their experience in operations following the Tsunami in 2004 and the Lebanon crisis in 2006 (Lundberg & Rankin, in press; Trnka, 2009; Trnka et al., 2009). One of the themes
covered in the focus groups was the command team members’ experiences of flexible roles. Both positive and negative issues were identified.

Positive effects:

- Getting the work done despite lack of resources.
- Team-building effect as it provides an opportunity to better understand other peoples work.
- Flexible roles increased endurance of the team as a whole.

Negative effects:

- Persons acting outside their field of expertise are less efficient.
- Workload may increase due to inefficient organisational structure and ineffective planning.
- Persons in improvised roles may burden other team members as they require continuous advice.
- A problem with a less structured command team is that people may get stuck in temporary roles.

Other aspects of role improvisation were also discussed. For example, individual and team attitudes were thought to be a determining factor to successfully taking on other roles. The quality of performance was also seen as dependent on workload, as pre-defined structures appear to be more efficient during low workload. A strong management team may sometimes be necessary to help people get out of roles once they are in them. The participants also felt that training does not address these issues enough. More varied training scenarios with different structures and settings would be useful.

### 4.1.3 Results and Analysis

Results from the in-depth analysis suggest that there is a decrease in the quality of performance when acting in an improvised role. The analysis of communication and information sharing of the command team offers a closer look at factors contributing to successful and less successful adaptations. For transcribed examples of the communication see Paper 1.

The first impression given by the simulation participants, observers and exercise managers was that the team had accomplished the tasks with great success by restructuring the command team to cover all critical functions. However, the subsequent analysis reveals another side. Critical parts of information had been misinterpreted which could have had severe side-effects further down the line. Misinterpretation of information includes, for example, the type of face-mask protection necessary and where these can be acquired. Further, there was a mix-up of emergency phone numbers. The confusions appear to stem
from a combination of problems within the team, including three main areas: language and communication, domain knowledge and organisational structure (Table 1).

### Table 1. Summary of factors contributing to the misunderstandings

<table>
<thead>
<tr>
<th>Main reasons for misunderstandings</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Language skills and communication</td>
<td>• Did not pick up on contradictory information</td>
</tr>
<tr>
<td></td>
<td>• Misunderstanding due to grammatical mistakes</td>
</tr>
<tr>
<td>Expert (domain) knowledge</td>
<td>• Hazardous smoke</td>
</tr>
<tr>
<td></td>
<td>• Protective filters used in face masks</td>
</tr>
<tr>
<td>Structure (organisation)</td>
<td>• Unclear responsibility</td>
</tr>
<tr>
<td></td>
<td>• No formal handover</td>
</tr>
<tr>
<td></td>
<td>• Insufficient spreading of information</td>
</tr>
</tbody>
</table>

The overall English language skills of the Swedish team were good and the participants had previous experience of international operations. However, several key-factors are misunderstood when receiving information from the American authorities. For example, information received about what protective masks to use was initially misunderstood. Although information contradicting this initial misunderstanding kept being presented to the team, it was not fully understood or acknowledged. The organisational structure of the command team (e.g., hand-overs, joint briefings) plays an important role not only to share information among team members, but also to detect misunderstandings and conflicting information, as is demonstrated during the joint briefings. However, a lack of formal hand-overs and clarity in task responsibility lead to information getting lost and distorted. The results suggest that a better structured organisation would have had a substantial impact on information sharing which could have revealed some of the misinterpretations.

**Multiple contributing factors**

The team is unexpectedly faced with a large reduction in staff and multiple trade-offs are made as the team strives to complete their mission tasks with reduced capacity. Although most tasks are performed successfully the team is faced with a continuous stream of new information and issues that need to be dealt with, and with little time to do it, causing several failures to adapt.

As the disturbance includes the loss of resources and expert domain knowledge, system brittleness in this area is to be expected. However, factors not directly linked to the loss of certain functions appear to contribute to the failure to adapt. These factors include task
responsibility and information loss within the team. Information systems are not used in efficient ways, leading to important information not reaching the right team members. Further, several participants are expected to manage their regular task well as they take on tasks outside of their field of competence. Managing two roles appears to have caused a bias toward one's professional role. Tasks are left without anyone formally responsible for them and proper hand-overs are not carried out, causing important information loss. The joint log, which could have served as a support system to keep track of the latest information, was only partially up to date and not used to its full potential. A summary of factors affecting the team’s performance are illustrated in Figure 3.

Figure 3. Model of information flow in the Command Team

Figure 3 demonstrates how different factors affect the command team’s ability to cope with tasks outside their field of competence. The illustration starts at the top left with an individual taking an improvised role (1) to fill in for an expert missing from the team (0). This individual lacks knowledge about key terms and facts (2). Tasks outside his/her field of competence are assigned (3). This may result in either (4) correct information given, or incorrect information being given. Factors positively affecting management of the tasks are depicted on the inside of the white ring: communication with expert, joint briefings, information being logged in the joint log book and hand over of task. Factors negatively affecting management of the task are: misunderstandings caused by language problems, incorrect information sharing, lack of domain knowledge in the group to discover errors, log not used by team members and hand-over not performed.

Improving the ability to take on flexible roles

The system’s ability to manage the disturbance is identified as stemming from multiple sources. As the team adapts it is important to identify the opportunities and vulnerabilities of the new team structure. Based on the analysis of the simulation three suggestions for
improving the team’s ability to support flexible roles are: (1) training to take on the responsibility for tasks and roles outside one’s professional area of specialization, (2) develop more formal routines for hand-overs of roles and tasks and (3) improving routines for information sharing.

4.2 Adapting to cope with everyday situations
The first study demonstrated the importance of understanding the interplay of different factors affecting a team’s ability to adapt. In the second study we examine a set of examples where people adapt to cope with disturbances in their everyday work environment.

Results from Paper II are presented in Sections 4.2 and Section 4.3. In Section 4.2 examples of everyday situations where people have to adapt collected during the focus group studies are presented. Section 4.3 presents a framework for analysing adaptations.

4.2.1 Overview
The study was exploratory with the objective of getting practitioners involved in cross-disciplinary discussions on learning from “what goes right”. Discussions were centred on work situations where human adaptations are critical, that is, near the margins of safety. Focus group discussions provided examples of situations where people adapt their performance to deal with the demands of their everyday work environment. In some of the examples the system successfully manages to cope and in other situations they do not. The analysis of the examples focuses on how adaptive behaviour in complex socio-technical systems can be structured and analysed. This work resulted in a framework for analysing adaptive performance.

4.2.2 Results and Analysis
Three situations are presented below, demonstrating the complexities and interactions involved in everyday work. More examples can be found in Paper II.

Example 1: Medicine packages

Medicine packets from pharmaceutical companies in Sweden sometimes look very similar. Highly potent medicine can therefore be placed next to, and look similar to, commonly used medication. For instance, an ampule containing 10,000 units can look exactly the same as an ampule containing 100,000 units, apart from an extra “0”, even though the medication containing 100,000 units is very potent. Usually, before giving medication, a nurse will put a label on the syringe, entering information about the type of dosage of the medication, also double checking the label on the original package. However, in a state of emergency time is critical and these barriers are often bypassed. To minimise the risk two different hospitals reported using local adaptations to create a more robust situation. At one hospital the adaptation includes organising the
medicine room, emergency carriage and operating room in a certain way. A second hospital solves the problem by ordering different potencies from different pharmaceutical companies, resulting in different coloured ampules. The sharp end personnel report this as a very effective strategy.

The colour coding strategy, not known outside of the hospital division did, however, in one instance, prove to cause an increased risk, as outside circumstances changed. The pharmacy, which places the orders based on requests from the hospital, got information from the regular supplier that this particular medication was unavailable. The pharmacy then went ahead and ordered the medication from a different supplier, not aware that this change in ampule colouring could cause a great risk if not recognised by nurses.

The system becomes increasingly vulnerable as it shifts into emergency mode. Time constraints in an emergency may cause barriers to be bypassed such as double-checking the label on the syringe. The sharp-end strategy of organising and colour coding the medicine then provides an extra barrier. One of the strategy enablers is that a particular colour on the medicine packets is available. If it is not, the strategy may cause a greater risk than had the strategy not been there at all.

The pharmacy representative, on the other hand, does not know that ordering medicine from a different pharmaceutical company might cause confusion for the nurses, and did not even think to notify anyone about the change. The example demonstrates how an adaptation to increase safety locally can cause brittleness when not acknowledged in other parts of the system.

Main point of the analysis:

- System design (medicine package colour) creates risks in the everyday work environment. Current procedures and barriers do not sufficiently cover the risks during emergencies.
- Local adaptations of work environment are developed at the sharp-end to minimise the risks.
- The adaptation works well locally but may create a new risk as circumstances in other parts of the system change.

**Example 2: The train scenario**

On some types of intercity trains in the Stockholm area, Sweden, passengers late for the train run after it, open the doors and get on when it is already in motion. This happens relatively frequently, in some areas on a daily basis. Although it is against the law, it is rarely reported as an incident as it is considered “normal” and severe accidents have occurred, even with fatal outcomes. One of the problems with solving this issue is a law within the EU stating that train doors cannot be locked if there is a step and handle on the outside. Further, the step and handle cannot be removed as the shunting personnel need them to perform their work. Incidents are often avoided thanks
to intervening staff. To deal with the situation the staff report that (1) the train driver slows down if he or she detects a passenger trying to get on and, (2) conductors (or other staff members) push or pull passengers on or off the train. In an attempt to improve the situation SJ (rail operator in Sweden) has enforced a new rule stating that the train doors should be closed 30 seconds prior to departure. This is, however, not enough to eliminate the problem, and local adjustments are still made.

The recurring hazardous situation of passengers trying to get on-board the train as it is leaving the platform requires the staff to adapt new strategies, adding workload to their usual repertoire of tasks not included in the procedures. The added workload means they the train staff shift part of their attention from their regular tasks in keeping the system functioning and safe. This could be, for instance, assisting passengers, ensuring luggage is safely stored and checking tickets.

Main points of the analysis:

- System design (train doors, handles and steps) create risks in the everyday work environment
- Blunt-end effort to minimise the risk is helpful, but not sufficient.
- Local adaptations to cope with the risks are developed at the sharp-end.
- Local adaptations produce an increased workload for the train staff which may have other consequences in the systems such as leaving regular tasks unattended. This could be a potential source of brittleness.

**Example 3: Following procedures at the hospital**

A patient is having a contrast medium injected prior to a contrast X-ray. For this type of injection the procedures says to use a thicker needle. However, some patients are difficult to inject and a thinner needle is therefore sometimes used.

One time a nurse had already tried multiple times to inject a patient with the thick needle without success. This was, of course, very unpleasant for the patient. To alleviate some of the discomfort the nurse tried a thinner needle. As the nurse was aware that this could pose a risk when injecting the contrast medium she made sure the placement was secure by inserting a saline solution. The patient was then moved to the X-ray ward and a different nurse injected the contrast medium. The connection burst and the patient had a severe allergic reaction.

One way to describe how system constraints and situational conditions shape human behaviour is through trade-offs (Hoffman & Woods, 2011; Woods & Branlat, 2011). The term trade-offs implies that simultaneous goals are not aligned; fulfilling one criterion may cause difficulties in achieving others. In this example the nurse had multiple goals to achieve; (1) ensure that the patient gets an X-ray (2) ensure it is done safely and (3) minimise discomfort to the patient.
In this situation, the nurse fails to apply the needle multiple times, creating discomfort for the patient. In trying to fulfil the previously stated goals the nurse resorts to a well-known method at the ward; applying a thinner needle. This act is not part of recommended procedure as it may cause problems when injecting the thick contrast medium. Hence, the nurse compromises one of the goals (ensure safety) to try to accomplish the others. She successfully manages to apply the needle and then makes an additional assessment by testing the needle to ensure it is safe. However, on this particular patient, it did not work and when the contrast medium was injected the patient had a terrible reaction.

Main points of the analysis:

- Trade-offs have to be made between several, sometimes conflicting, goals.
- To achieve some goals, others may be compromised.

The three examples presented above demonstrate some of the complexities faced by sharp-end people in everyday situations. Clumsy design of the systems, situational conditions, external factors, multiple and conflicting goals are all part of shaping the outcome of a situation, making systems intractable. These results underline previous work that making interpretations of a failure to adapt based on what "should" have been done is not sufficient to understand what the problems are. To minimise hazardous situations it is not enough to analyse one failed situation. Instead it is necessary to explore the context, the complexities and the conflicts that shape the risks. Through structured and systematic analysis we can better understand the constraints and trade-offs of the situation.

4.3 A framework for analysing adaptive performance

The strategies framework has been developed as a tool for structuring and analysing adaptations. Models and methods for capturing abilities associated with resilience are still rare, and this framework is a starting point for systematic gathering and analysis of adaptation-enabling factors and their relation to organisational pressures shaping the working environment. Increasing awareness of "work-as-done" and its effects on other parts of the system can help improve safety through foresight, preventative measures and mitigation of risks.

4.3.1 Results and Analysis

The strategies framework is a tool to describe and analyse adaptations (here described as strategies) in everyday work situations in complex work environments. The categories in the framework target three main areas: (1) an interpretation of the situation in which the strategy takes place, (2) enablers for successful implementation of the strategies (3) strategies effects on the overall system.

At the centre of the framework are the strategies. As illustrated in Figure 4 five main categories for analysing the strategies are included. The categories aim to uncover different
aspects of situational circumstances and constraints affecting the ability to use the strategy. The purpose of each individual category is described below.

**Figure 4. The strategies Framework**

*Forces and situational conditions* include an analysis of the situation in which a strategy is used. This analysis should provide the analyst with questions of *why* the strategy was implemented, which has a close relation to the objective of the strategy (see below). The analysis includes forces such as economy, efficiency, and safety culture as well as situational constraints such as time and resources. The depth of this analysis may vary but can be rather comprehensive as many factors are important to fully understand the situation. For in-depth studies other methods can be used in combination. For instance, established methods for accident investigation and risk analysis within a particular organisation can be used to target this area of investigation (Lundberg, Rollenhagen, & Hollnagel, 2009; Lundberg, Rollenhagen, Hollnagel, & Rankin, 2012).

*Resources and enabling conditions for the strategy* look at enablers of the strategy. This answers the questions of *how* the strategy is implemented, i.e., what the necessary requirements are. The analysis includes, for instance, time and resources, competencies and qualifications, decisions that have to be made and particular contextual conditions to enable the strategy. The category differs from the one above in that it is not focused on what created the situation but on what allows (or hinders) the strategy from being carried out in the situation. This reveals information on the systems flexibility in terms of actions and resources, or its *margin of maneuver* (Woods & Branlat, 2010). The two categories complement each other.

*Objective* should help the analyst understand the intentions and goals of the strategy. A situation may involve multiple, or conflicting objectives. It is important to view the objectives in the light of the forces and situational conditions.
The four cornerstones represent the four fundamental resilience abilities anticipating, monitoring, responding and leaning, as described by (Hollnagel, 2009). The strategies may pertain to one, or several, of these abilities. Including these as part of the framework will help identify system capabilities with reference to the type of disturbances faced.

Sharp-end and blunt-end analysis focuses on how strategies are supported on different levels of the organisation. Is the strategy supported (or acknowledged) by the managerial levels? If the sharp-end-blunt-end interactions work well, this demonstrates an evolving and learning system. The need to adapt can be a potential signal about systems’ vulnerabilities, such as insufficient work procedures or changing situational circumstances, and it is therefore important that it is acknowledged at the blunt end.

An Illustrative example

To demonstrate the use of the framework an analysis of “the late train passengers” presented in Section 4.2.2 is used (Figure 5).

Train passengers trying to get on a train already in motion as it is leaving the platform can cause disruptions. Several incidents have occurred in the past, including fatalities. The Swedish rail system and the train staff have adopted strategies to try to ensure passenger safety, although this does not entirely eliminate the posed threat.

**Figure 5. Analysis of train scenario using the strategies framework**

The forces (EU regulations) are there to ensure safety for shunting staff and are external to the organisation, making them difficult to affect. However, the analysis shows how the sharp and blunt-end work together within the organisation to manage the situation. The blunt-end acknowledged the problems and provides support by enforcing the 30 second
rule. This, however, only partially helps the sharp end, and their local strategies of pushing and pulling people off the train still have to be implemented.

The strategies demonstrate system ability to monitor and respond in situations which may be potentially harmful. The resources and enabling conditions shows that the strategies require increased resource capacity and an on-time schedule which may not be available at all times. This means that minor alternation such as passengers requiring assistance or delayed schedule could cripple the strategies.
In this chapter results from the studies are discussed (Section 5.1, 5.2 and 5.3) and suggestions for future work are presented (Section 5.4).

5.1 Adaptations and the quality of work

The results from Study 1 suggest that there is a decrease in the quality of performance when acting in an improvised role. Several factors are identified as underpinning the decreased performance where the command team members were forced to take on roles for which they lack professional training. The three main factors are: language skills, domain knowledge and organisational structure. What is particularly interesting is how important the factors are in relation to one another. The analysis suggests that if no misinterpretations based on language and communication skills would have taken place, domain knowledge would not have mattered and vice versa. The third factor, organisational structure, stems from the situational and contextual support given to participants taking on other roles. The analysis suggests that better organisational support may have had a substantial impact on the success of the tasks performed by participants in improvised roles. A lack of formal hand-overs and clarity in task responsibility leads to information getting lost and distorted. Further, there are indications that a better structured organisation would have revealed some of the misinterpretations. So, although initially the systems’ vulnerability is caused by the loss of resources and expert knowledge, the adaptation creates new vulnerabilities which are not detected and managed by the system.

The results from the simulation analysis support the results from the preceding focus group study (Lundberg & Rankin, in press). The focus groups participants felt that one of the greatest benefit of taking on improvised roles is that work gets done. However, the focus group participants also identified some drawbacks from their missions such as the quality of
work and the danger of getting stuck in the wrong task. The same results are found in the command team simulation. The team responded quickly and efficiently to the initial disturbance and successfully adapted by re-organising the command team structure to cover all necessary functions. However, the organisation was now functioning in a fundamentally different way, creating new system vulnerabilities through an inefficient organisational structure with unclear responsibilities. The combined results demonstrate that system flexibility comes at a price as new vulnerabilities surface as a system adapts to cope with the disturbance.

5.2 Adaptation reverberations

Although frameworks for analysing resilience potential are starting to appear (e.g., Furniss, Back, Blandford, Hildebrandt, & Broberg, 2011b; Hollnagel, 2011b; Leveson, 2011), interpreting and dealing with their side-effects have not received much attention. The phenomena that change in one part of the system has unanticipated consequences in other parts has, however, been noted in, for instance, human factors studies of the effects of introducing new technical systems (Cook & Woods, 1996; Nemeth et al., 2007; Woods, 1993).

The situations analysed in this research show that monitoring adaptation reverberations in both the long and short term is important to keep track of how systems change over time, what vulnerabilities may surface and what the capacity to withstand disruptions are. As was noted in the previous section adaptations may affect the quality of work in the short term. Similarly many minor adaptations that go unnoticed in the everyday work may, over time, have a substantial impact on the overall system. The ability to monitor and detect adaptation reverberations is useful in mitigating potentially undetected risks created by system variability, forces and situational conditions. For example, an adaptation that has a positive effect in one part of the system may affect another part of the system negatively. This could be due to, for instance, shifts in resources, re-distribution of knowledge and the re-organisation of a team. In Paper I there was a short term trade-off between, on the one hand, adapting to meet the needs of situation and, on the other hand, increasing the system vulnerability as non-experts perform critical tasks. However, the vulnerabilities of the situation were not detected and managed. The medicine package example in Paper II shows an adaptation has been implemented as part of regular work for the sharp-end personnel and was considered to be an effective strategy. However, as things changed in other part of the system the strategy could have had devastating effects as the adaptation was not acknowledged in other levels of management.

As the examples have shown today’s systems are intricate networks of people and technical support systems and their complexity cannot be fully untangled and modelled according to textbook scenarios. It is therefore important to detect patterns of change, and the effect it is having on the system. Rather than label performance according to previously defined “rights” and “wrongs”, it is critical to learn from what each event tells us about system
resilience and brittleness and try to identify “the bigger picture”. Just as previous research has shown that successful improvisation it is not an ad-hoc activity (e.g., Mendonca & Fiedrich, 2006; Vera & Crossan, 2004; Vera & Crossan, 2005) opportunistic adaptations to cope with the situational demands in critical situations are less likely to succeed than those enabled by the system structure. For example, had there been a better organisational structure in the crisis simulation, the misunderstandings would likely have been detected. To identify safety enablers such as these systematic monitoring and analysing adaptive performance must be carried out.

5.3 Analysing adaptive performance

The strategies framework should be seen as a tool to aid the analyst structure information about adaptive performance. The development of the framework based on examples across domains suggests that the same overarching categories can be used to analyse situations in different work settings. We argue that systematic identification and analysis of adaptations in work situations can be a critical tool to unravel important elements of adaptive behaviour in complex systems.

Framework application

The framework can be used by researchers and practitioners in safety management as a complementary perspective to established incident investigations and risk analysis by highlighting not only systems’ weaknesses, but also system strengths. Systematic use of such an analysis can provide valuable information on how to strengthen system resilience and mitigate system brittleness.

The framework can be used by practitioners at all levels of an organisation as a discussion guide to increase awareness of work practices and work patterns at the workplace not explicitly available through procedures and other documentation. Although sharp-end staff may be aware of strategies used in their work team, they may not have considered potential in other parts of the system. Directed attention to informal knowledge in or between workgroups allows insights to their own and others’ abilities to cope with the dynamics of their work environment. This may be useful for successful management of future disturbances and unforeseen events.

The framework may support retrospective and prospective safety management activities. Adaptations can be analysed in the aftermath of events (retrospective), and used to identify patterns which can be used to monitor system abilities and predict future trends (prospective). Results from systematically applying the strategies framework retrospectively can provide useful information for making predictions on how changes (e.g., increased production pressure or the introduction of new technology) may affect the overall system. The framework is thus a starting point for both researchers and practitioners to identify
critical enablers and systematic analysis of adaptations that may not surface through traditional safety reporting mechanisms.

5.4 Future work

The framework is an initial step, and further studies are encouraged to evaluate and develop it. The development of the framework is based on examples from multiple domains, demonstrating that a general model for understanding human adaptation can be used across work environments. To allow a more comprehensive view of underlying factors and their relations to adaptive behaviour over time examples from the same work environment should be gathered to allow a broader sample of performance. Interactions between contributing factors in different situations (but in the same environment) are important to gain an understanding for their effect on the system. This allows patterns of adaptive processes to emerge, including an understanding for what enables the adaptations and how it may affect other parts of the system (see Figure 6).

**Figure 6. Patterns of adaptations through analysis of multiple strategies**

A second area for further development of the framework is to include adaptation reverberations in the analysis. As the system changes due to adaptations, new opportunities and vulnerabilities may surface. To be resilient these effects must be identified and
monitored. The framework would then demonstrate the iterative process of adaptations effecting system which changes, requiring further adaptations.

A third area for further development is to integrate the analysis into current methods used in industry. This could be, for instance, by including the framework categories and perspective as part of incident analysis. Further, to enable full use of the framework sharp and blunt end personnel must be trained to identify and report situations of resilience, such as when they have to rely on unplanned or undocumented strategies.
6 Conclusions

It is not only when adaptations critically fail (e.g. incident, accident) that it is of interest to examine them. All adaptations outside expected performance provide information about the current system state, its adaptive capacity and potential brittle points. Failures to adapt, successful adaptation or partially successful adaptations are all key pieces of information in unravelling the complexities of everyday work in dynamic environments. Although this has not previously gone unnoticed, there is a lack of knowledge and recognition of what creates and enables successful adaptations, particularly in time critical situations where current procedures are not sufficient.

This research has contributed to previous literature by highlighting that there is a need for new perspectives in safety management. The observations and stories collected in the studies show a different story than the textbook situations of what people do at work. Procedures, instructions, barriers and system design are not sufficient to cope with the dynamic work environment of complex systems and people adapt their performance to meet these uncertainties. The results thus demonstrate how a complementary perspective to traditional safety perspectives (see Chapter 2) can benefit our understanding and interpretation of system performance in socio-technical systems.

A significant finding from the analysed examples is the importance of analysing adaptation reverberations. Adaptations that have a positive effect in one part of the system may have unanticipated side-effects in other system parts. Over time, many minor adaptations may have a significant effect on the overall organisation. Although each individual decision to adapt may be locally rational, the effects on the greater system may not have been predicted and far from what was intended. This point further highlights the need to monitor and analyse where things “go right” as their effects are difficult to identify and anticipate if not
recognised by the system. By monitoring and learning from adaptations it is also possible to recognise what combinations of situational circumstances, forces and goals create system brittleness as the system is forced to adapt. Similarly, the identification of adaptations allows insights into the individuals, teams and organisations adaptive capacities (resilience), and provides important information for system design. It can also make information available on what enabling conditions are necessary for successful adaptations to cope with certain disturbances.

The framework developed as part of this research can be used by researchers and practitioners to structure and analyse sharp-end adaptive performance. The framework can further be applied to enhance current methods used in industry today. The integration of resilience terminology into current safety management can provide insights into essential enablers for successful adaptive performance that may not surface through traditional reporting mechanisms. Analysing sharp-end work not only as it goes wrong but also what enables it to go right offers new perspectives on how to improve safety and the ability to deal with unexpected and unforeseen events.
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