IMPROVED RISK EVALUATION AND IMPLEMENTATION OF RESILIENCE CONCEPTS TO CRITICAL INFRASTRUCTURE

Organisational resilience concepts applied to critical infrastructure

Staffan Bram [1]
Helene Degerman[1]
Laura Melkunaite[2]
Terese Urth[2]
Elisabete Carreira[3]

1. SP Technical Research Institute of Sweden
2. DBI
3. INOV

Deliverable Number: D4.3

Date of delivery: November 30, 2016

Month of delivery: M18

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 653390

Coordinator:	David Lange at SP Sveriges Tekniska Forskningsinstitut (SP Technical Research Institute of Sweden)

Table of Contents

1 Executive Summary

This study starts with a literature review concluding that outline of organisational resilience should be selected to serve exposing new ways of analysing organisations, giving new perspectives on system safety and efficiency. Based on this conclusion, resilience as flexible adaptation was taken as a baseline definition for the use in the following studies.

In an organisational context, organisational resilience was described as the ability to…

- Constantly re-assess itself and the situation using a diverse set of skills and knowledge
- Engage all parts of the organisation in idea generation and problem-solving
- Adapt and re-invent itself when faced with unexpected events
- Build the right support for sensemaking and action based on a profound understanding of practical working conditions
- Make decisions based on a firm understanding of real-world operations the current situation and the need for trade-offs
- Collaborate in a dynamic network of actors
- Stay humble in relation to the predictability of real-world operations

Since organisational resilience depends on a broad set of organisational features to develop, the study of this subject must be equally systems oriented. A systems oriented approach means paying close attention to the interactions within the system. This is coupled with a socio-technical approach, where the interplay between human, technological and organisational elements of an organisation is examined.

The report concludes that it may be difficult to integrate resilience into typical indicator follow-up activities. The study of organisational resilience requires a situated approach where work is studied from many perspectives, in context. The extent, to which such studies can be transformed into indicators where the results can be used in a meaningful way, could be questioned. Furthermore, the common use of indicators can also stand in conflict with the development of resilience. In conclusion, while it is important to know what to look for, it is equally important how to look for it, and perhaps even more – how to affect those things that are studied. For an organisation to support resilient performance it has to make serious investments, not least mentally, in human-centred practices for management, design and collaboration.

A case study was performed and societal infrastructure actors were interviewed. In the analysis, the extent to which the studied organisations were able to perform resiliently is to a large extent connected to certain values, for example their way of relating to established rules, regulations, procedures and processes, the way relations were formed between people and hierarchical layers within the organisation, or the perceived value of the human operator in the organisational whole. These values, in turn, determine how the organisations shape many of the basic conditions that allow resilient performance to develop.

As an overarching theme it was concluded that striving for resilience is not only about knowing what organisational abilities to boost, but more about the way in which such abilities are sought. One such condition for resilience is the design and re-design of all organisational artefacts such as functions, processes, environments or tools. A second condition is the nature of internal and external collaboration, where the focus must be on actual human interaction and common problem-solving for good collaboration to evolve. A third is organisational learning that pays respect to the experiences of operational work, and that feeds into a structured process for re-designing the organisation.

2 Introduction

2.1 Background

Today's critical infrastructure is marked by increasing complexity and tighter coupling to other societal functions. At the same time it has proven difficult to describe decision-making under complex and unusual conditions from a classic decision science perspective, which means that there is little room for automation and that the human actor remains an important asset (Caldwell, 2015). Indeed, this human capacity to handle unexpected situations and solve ill-formed problems is by some authors tied closely to the concept of resilience (Erik Hollnagel, 2012)

This report is centred on the concept of organisational resilience and begins with a literature review covering definitions and other findings from the industry, complementing and commenting on those found in other IMPROVER reports. Findings are reviewed for clues to how resilience in organisations can be approached empirically. This review forms the base of a study in the IMPROVER living labs. Findings from the labs and the literature review are then condensed into a summary of possible indicators of organisational resilience.

2.2 Purpose and objectives

The purpose of the work described in this report was to aid practitioners in infrastructure to promote resilient abilities within their organisations.

The **primary objective** was to provide new knowledge about organisational resilience by studying real-world examples of how organisations in critical infrastructure tackle challenging situations.

The **secondary objective** was to show how such expressions of resilience can be examined and the outlook of doing so with existing methodologies.

Further, this report contributes to the overall **objectives** of Improver; understanding resilience, evaluation resilience concepts and development of a resilience management methodology.

2.3 Delimitations

The underlying structures and reasons for societal driving forces have not been analysed, for example economical mechanisms and politics.

2.4 Outline of report

Chapter 3 describes the methodological approach in the various stages of producing this study.

Chapter 4 gives a theoretical background, touching on the development of the concept, definitions of resilience and core conditions for organisational resilience to develop.

Chapter 5 describes the performed case studies and the analysis of obtained data.

Chapter 6 deals with identifying potential indicators for organisational resilience, based on the previous chapters.

Chapter 7 contains a discussion of certain salient themes in the report.

Chapter 8 presents the overall conclusions of this study.

3 Method

The work described in D4.3 is made from a systems perspective. A crucial starting point in analyses from this perspective is that the relations and interactions between sub-systems, humans, the organisation and artefacts are essential for the performance of the overall system, not the parts themselves. Therefore we need an analysis from different perspectives and levels, and the result is always dependent on how and with what purpose the system is analysed (Hollnagel & Woods, 2005).

The approach in this work has been iterative. New aspects are always discovered during the way and the iteration leads to a bigger match to reality (Hollnagel & Woods, 2005). A case was used when interviewing and analysing the empirical data.

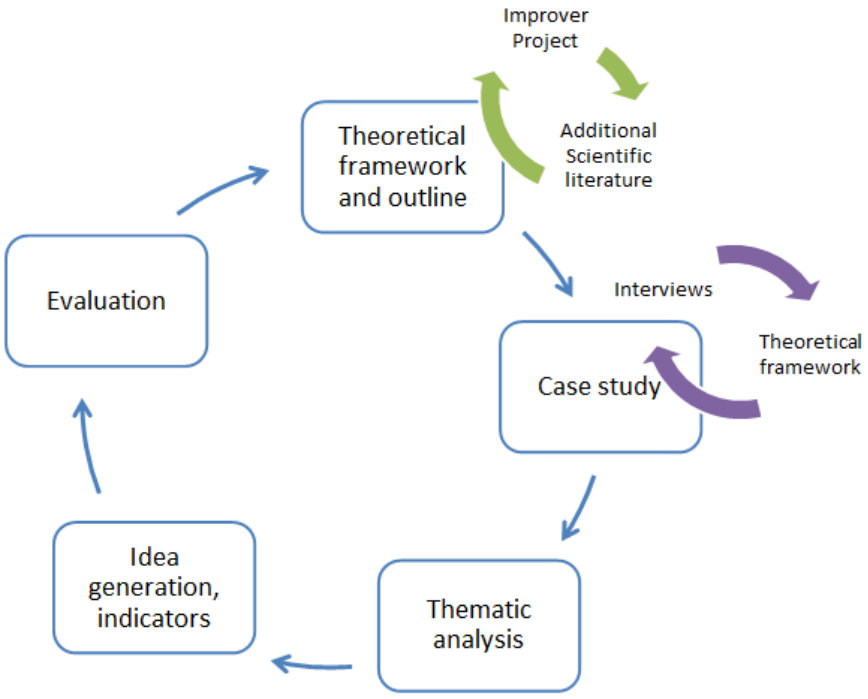

Figure 3.1 Schematic representation of the iterative method

The case study was found as a suitable method for the WPs scope and helped the informants to relate to something. The method gives opportunities to combine different sources of empirical data and to specify detailed research questions and objectives a bit later in the work (Ejvegård, 1996).

3.1 Theoretical framework and outline

In these WP's a study of scientific literature related to resilience has been performed. The study has resulted in a theoretical framework, see chapter 4, that functioned as a reference point in the analysis of the empirical data in the case study. The framework and outline of organisational resilience were made in a small iterative loop, see Figure 2.1, between earlier scientific literature studies in Improver and an additional literature study focusing on organisational aspects.

It is relevant to discuss this deliverables interpretation of resilience since prior understanding and paradigm contributes a lot for the result of the study (Alvesson, 2011). Resilience is understood and interpreted in various ways. This contribution mainly related to the research discipline that focuses on interactions between system parts and recognises the context as complex (Hollnagel & Woods, 2005). Then it is important that the research is performed in the actual field, out in the wild and not only in a controlled lab environment. A prerequisite is that interactions, relations and flows changes in different

contexts, since the context also affects relationships between humans, technology and the organisation (Hutchins, 1995).

3.2 Case studies

Case studies have been made in the Improver Projects living labs (the Öresund region and fresh water supply in Barreiro, Portugal). The purpose with conducting interviews was inspired by Woods (2015), that says *"attempts to understand rebound, first, should change direction: search for previous disrupting events and analyse what the system drew on to stretch to accommodate those kinds of past events".* Thus, we looked for resilient organisational aspects in talks about a passed event.

The collection of empirical data was made in a small iterative loop, see Figure 2.1. Aspects that were identified in an interview sometimes needed to be validated through new interviews and literature and the other way around.

3.2.1 Interviews

The interview guide was based on the objectives in the study and functioned as a base line for creating more detailed interview questions. The interviews also helped in creating a deeper picture of the problem description and a more multilayered image of the case in the study. The interview guide is found in Appendix 1.

The same guide was used for all informants, and all questions were not applicable in all interviews. Therefore the guide had to be adapted more or less for every interviewed person/organisation. The interviewer was allowed to ask follow-up questions and ask for examples and clarifications. The team responsible for developing the interview guide performed interviews in Sweden. The interviews in Sweden were semi-structured, due to a greater knowledge about the purpose behind the questions. Interviews in Sweden were tape-recorded or Skype-recorded. At one interview occasion notes were taken because of technical problems with the recording. Quotations were transcribes when re-reading and re-listening to interview. In Denmark and Portugal more structured interviews according to the guide were conducted by Dbi and INOV. In Portugal and Denmark interviews were tape recorded, transcribes and translated to English.

3.2.2 Informants - Öresund region case

Interviews have been performed with organisations as follows (including a short description of role regarding the case):

Swedish Migration Agency

The governmental authority responsible for receiving and examining asylum applications. Responsible to provide accommodation and food to asylum-seekers (families and single adults) while they wait for a decision.

Malmö municipality

Responsible for providing unaccompanied refugee children with accommodation, food, care and legal guardians. Malmö municipality also owns the land outside the railway station, "Posthusplatsen", where different organisations co-organised support functions in barracks.

Swedish Civil Contingencies Agency (MSB)

Supported the Swedish Migration Agency in staff function methodology in crisis according to an agreement reached at a high organisational level between the authorities.

The Swedish Armed Forces

Supported the Swedish Migration Agency with organising the staff function in a more concrete way, after making their own view on the needs in the Malmö staff.

Jernhusen

Property manager for Malmö railway station, where lots of refugees arrived as first stop in Sweden. Jernhusen's patrolling guards could identify the increased refugee flows early. They organised and donated space and functions within the station's walls. Jernhusen donated conference rooms for involved organisations to meet twice a week.

Swedish Red Cross

Established NGO that worked closely with the authorities. Were represented at Posthusplatsen in a barrack. The organisations at Posthusplatsen had agreed on following Swedish legislation, that means only helping people with the intention to seek asylum in Sweden.

Danish Red Cross

Kontrapunkt

Civic and social association and center in Malmö who engaged mainly by offering accommodation and food within their facilities. They collected money through appeals on social media and could help refugees on their travel through Sweden. They helped people regardless if they were asylum seekers in Sweden or not. Kontrapunkt did not have a close collaboration with Malmö municipality or Swedish Migration Agency

The Øresund Bridge, Sweden

The Öresund bridge consortium, half owned by Sweden and Denmark. They collaborate with Swedish and Danish police forces and authorities to donate land and structures for the Swedish Police conducting border controls. The traffic management controls road traffic through the tunnels and on the bridge.

The Øresund Bridge, Denmark

The Danish side of The Öresund Bridge consortium.

DSB Trains

Train staffing in DSB including traffic information. Operating unit stationed at Copenhagen Central Station. The role for the organisation was to ensure transportation of customers, regardless their origin.

Danish National Police Force

Swedish Police force

Interviews could not be conducted within the time limit for the deliverable.

3.2.3 Informants – Barreiro cases

City Hall of Barreiro

Câmara Municipal do Barreiro (CMB), in the Water and Sanitation Division (DAS) of the Department of Water and Waste

Barreiro City Council

The executive body of the Municipality of Barreiro.

Municipality of Barreiro

The managing entity responsible for the design, construction and operation of the Public Water Supply System of the Municipality of Barreiro

3.3 Thematic analysis

A thematic analysis of the entire empirical and theoretical empirical body was made. A thematic analysis is a form of pattern recognition where themes evolve when structuring and analysing the empirical material as a whole (Bowen, 2009). The analysis process was conducted in a couple of iterations, for letting unidentified data get the chance to find its place in the analysis.

Focus in the analysis was identifying aspects related to resilient abilities and performance. Since these aspects aren't operationalised in most organisations today, it is hard to ask the informant direct questions about it. Therefore a thematic analysis was suitable, since such an analysis is conducted of the empirical data as a whole, not only from already predetermined rules.

Reflections on the empirical interview material have been performed from Alvesson's (2011) reflection approach and framework, where traditional notions of the interview (see for example Ejvegård, 1996) have been complemented with eight metaphors from social, psychological and linguistic nature. The analysis process has been reviewed by researchers not directly involved in the projects, this for identifying possible biases.

The thematic analysis has focused on identifying general areas and not on finding detailed measures. In line with Bowen's (2009) method description themes evolved during the process, where abilities that are important for resilience could be identified. The analysis in chapter 5 is presented from these themes. Further, the analysis of the themes was focus when discussing this study's aims in chapter 7.

3.4 Development of indicators

In the overall Improver Project, development of indicators for infrastructure resilience is a main objective. Since indicators as a representative tool for analysis in complex systems is critiqued, we viewed indicators as "something to look for and promote within an organisation". It is the most appropriate way of dealing with indicators in an organisational context.

This work began with a collection of resilient aspects and already existing indicators from the scientific theory. The interviews were conducted upon this theory and the total empiric body changed the indicators through the thematic analysis.

Evolving themes were sorted hierarchically and transformed into indicators on different levels. The work was made iteratively by the three method steps; identification of needs, idea generation and evaluation. Through the identification of needs a list of demands on the indicators was created. This is a common approach in use-driven design. The list of demands guided the development of indicators and helped in evaluating indicators. If an indicator didn't meet the demands it was revised.

We used Rasmussen's (1985) work on purpose/function/physical form for sorting the aspects of resilience hierarchically depending on their abstraction level. For organisational processes building resilience, we used resilient abilities as a purpose, the highest level of abstraction. The abstraction hierarchy then works as a framework for describing the functions, forms and detailed organisational processes needed for maintaining the organisational purpose – resilient abilities. The functions builds the purpose and the function depends on changes in organisational forms and processes, the function's physical form. Hence, the system purpose resilience could be described bottom-up (what builds resilience) or top-down (causes for a meeting the purpose or not meeting it).

However, the idea of being able to divide a complex system in a hierarchy is problematic. It is a logical non-contextual exercise, while real decision-making processes in everyday work or crisis is a complex analytical process (Salmon et al., 2014). Therefore, the set of indicators, or "what to look for and promote in an organisation for building resilient abilities" should not be fixed. One indicator must be that keeping the set of indicators alive and developing it according to changes in the environment and especially when logically produces routines and processes have been tested in reality. This is crucial.

While conducting the thematic analysis we re-read or re-listened to data from interviews. We transcribed quotations, and tagged and mapped the data according to a list of resilient aspects from the scientific literature study. The tags/codes/categories of interview data were mapped in a tree. On "branches" and "leaves" of the tree aspects of resilience in different abstraction levels were placed. The tree was further mapped against the hierarchical framework of purpose/function/form/process, directly translatable to different levels of indicators. This breakdown did not, and could not, show distinct boundaries, but the Rasmussen (1985) framework also allows to state that all functions must be present for reaching the purpose.

We particularly reflected around an aspect that is hard to visualise or even identify. It is the question of "values", or maybe the ontological and epistemological viewpoint from which the organisational work is performed. For example, it is not enough to view the system as complex; the complexity must be regarded as an environmental ecological prerequisite, not something that could be reduced by e.g. a high degree of standardisation, with the belief that it controls the unknown. "Values" affect the interpretation of the indicator and later the chosen measure. Andersson (2014) handled this in is dissertation by the aspects domain values, priorities and trade-offs (e.g. quality vs. productivity). Our ambition became to break this further down into indicators. The question about trade-offs, must certainly always present (Hoffman & Woods, 2011), is sometimes a delicate issue for organisations. It is easy to dismiss by stating that the organisation has both good quality and high production levels and that the organisation don't see a problem. The essence of reflecting around trade-offs is not driven by the belief that presence of trade-offs are bad. On the contrary, acknowledging complexity in goal conflicts and trade-offs could help the organisation guiding decision-making in crisis situations. We wanted to capture the essence of why and when an organisation manifests certain values in a meaningful way. What are the success factors; could we highlight this in a way transformable to an indicator?

4 Theoretical background and framework

In this chapter, the literature around organisational resilience is explored and a basis is formed for the execution of the case studies.

4.1 Motivation for introducing the resilience concept

When incidents occur in critical infrastructure today, effects are often wide-spread and may propagate to other societal functions. Failure is no longer equivalent with the existence of a broken component, but often results from interactions between people, complex technology and different environmental pressures (Milch & Laumann, 2016). This notion of complexity in infrastructure systems is reflected by the IMPROVER international survey of D1.1 and is also closely related to the idea of socio-technical systems in safety analyses, i.e. systems that involve complex interactions between humans, technology and workplaces (Erik Hollnagel, 2014). Problems that occur from interactions within a complex system will often cascade, steeply increasing the cognitive and coordinative demands on its human elements (Bergström & Dekker, 2014). Moreover, organisations are typically subject to many competing pressures, e.g. to become faster, better and cheaper (Woods, 2015). As the IMPROVER international survey points out, the realisation that socio-technical systems are becoming more and more complex and that this demands a change in focus for those trying to analyse systems has been growing in the ecological and sociological research communities for some time.

This report will build on findings from the literature review of resilience concepts presented in the IMPROVER international survey and in the IMPROVER lexicon but also on a literature review of safety science, the field of research occupied with the question of why operations in high-risk contexts succeed and fail. In this field, the notion of growing complexity has spurred a development during the last decades where a "systems perspective" has gained ground, meaning that analysts primarily focus on how organisational, social and man-machine interactions affect operational outcomes. Within the scope of this development, the underlying assumptions of many of the traditional elements of industrial safety have also been questioned, such as risk analyses, reliance on procedures and the wide-spread use of barriers for safety.

There are several reasons for including safety science as a background for the studies performed within this report. Firstly, this field of research has been occupied with studies of CI systems for many years, starting off with human factors analyses in the nuclear industry following the nuclear incidents of the 1970's and 80's. Complexity has been a common item within this discourse, not least in connection to the claim of Perrow (2011) that increasing complexity in modern industrial systems makes accidents more or less unavoidable. Secondly, the systems orientation within safety science has always included an organisational perspective on industrial safety, acknowledging that most of what happens in CI systems is connected to organisational attributes, processes or interactions (Bergström & Dekker, 2014). Moreover, while the systems perspective applied in safety science seems to be well in accord with the complexity and systems oriented framing of the D1.1 report, it also deepens the discussion in terms of human/machine/environment interactions in an organisational context. These themes and their implications will be developed further in the following sections.

4.1.1 Increasing industrial and societal complexity

Hollnagel (2012) connects the state of today's industrial systems to a definition of complexity found in the field of Cybernetics, where Norbert Wiener described it as "*the degree of difficulty in predicting the properties of the system if the properties of the system's parts are given*". In Hollnagel's view, coping with incidents and other changes in the environment must be based on predictions of some kind. This presupposes a sufficiently clear description of the system and how it functions. Some systems are tractable (stable and relatively easy to describe) while others can be described as intractable "if the principles of functioning are only partly known or even unknown, if descriptions are elaborate with many details, and if the system may change before the description is completed.".

Intractability does not only affect the system analyst, but more so the people who work trying to control the system's outputs. Because of the technical complexity of a CI system and the changing nature of its working environment, there is no way of using risk analysis to predict every single possible system state or output. Activities will not in all cases allow themselves to be described in procedures and plans. Instead, the human elements of the system will have to make adaptations, using their skills to interpret the situation, detecting deviations and making corrections when things go wrong. Complexity makes it so that work is always to some extent under-specified. From this perspective, contrary to the traditional view, humans are seen as a unique asset instead of an unreliable and risky system component.

4.1.2 A growing need for adaptive capacities

The need for adaptive capacities is a popular theme within safety research and it is also mentioned several times in the IMPROVER international survey, where it is traced to both ecological and economic theories on how systems change dynamically to become better at coping with disturbances. Underlying these ideas is a positive interpretation of human professional activities, something that is also emphasised in safety science and which has later contributed to the appearance of the concept of resilience in that field. During the last decades, industrial safety professionals have been occupied trying to create stability by restraining behaviour within their organisations. By means such as automation, increased use of procedures and specialisation, attempts have been made to eliminate perceived interference from humans in industrial processes (Moorkamp, Kramer, Van Gulijk, & Ale, 2014). These practices have been challenged by the research community. For example, while procedures may provide stability and common ground they never cover every scenario and may even limit the creative problem-solving abilities of professionals, and while it may seem like a simple approach to seek out vulnerable system components and build more defences, every added barrier or new technological feature will also increase system complexity, possibly increasing demands on the people controlling the process, limiting their chances of understanding the situation at hand (Patterson & Deutsch, 2015). Numerous studies of work in safety critical contexts have concluded that this unique human adaptive capacity is a core element of maintaining system safety. As the IMPROVER international survey points out, this is reflected by a number of national policies on emergency preparedness, for example the "all hazard" approaches of Australia, Canada, USA and Sweden. The rationale behind these approaches has been that all possible events cannot be foreseen and prepared for through specific countermeasures (D1.1). In the words of Grote (2004), rather than the traditional approach of trying to minimise uncertainty, the industry needs to find ways of supporting people trying to cope with uncertainty.

4.1.3 Contributions of a systems perspective on CI

One of the most common safety-related practices within the industry today is probabilistic risk analysis. But can these methods be expected to support the kind of adaptability beyond foreseen scenarios discussed in the previous chapter? The most common methods for risk analysis trace back to the early days of nuclear power development in the US where engineers were confronted with the complex task of building safety features into the first large-scale nuclear reactors. Because these technological applications were new there was little operational experience to guide design, something that made it necessary to develop new ways of modelling end performance. The logic was that if these installations could be demonstrated to handle certain worst-case incidents, then it could be demonstrated that any other incident could be handled as well. Similar developments were also seen in the US space program and in aviation (Keller & Modarres, 2005). PRA (Probabilistic Risk Analysis) is typically carried out in the form of fault trees or event trees, where events or possible faults within a system are drawn into a causal chain and where each item is assigned a probabilistic value, taken either from operational data or from guidelines.

Even though probabilistic approaches to risk analysis largely dominate professional safety work within many industries, these methods have lately been criticised by researchers from different fields, a criticism which is intimately tied to the notion of systems thinking in safety. For example, Leveson (

2004) notes that while traditional risk-based safety work is centred on boosting the reliability of individual components (because of each component's contribution to risk in the fault tree), component reliability does not necessarily imply safety.

First, it is possible for a system to be reliable but unsafe, i.e. even though all components perform reliably, a system can fail because of problems in the interactions within and between system functions. Moreover, this scenario should not only be considered for interactions in technical systems, but also between functions in a socio-technical system. In socio-technical systems, different trade-offs are often made around safety, and safety can sometimes stand in conflict with reliability. For example, the windows of a building can be made reliable in the case of an explosion, but the same windows may obstruct evacuation in case of fire, and a power plant may have a very reliable production although emissions are high. In short, a system may have competing goals or problems in internal or external interactions that limit its adaptive capacity.

Conversely, it is also possible for a system to be safe but unreliable. On the technical side, Leveson brings up the example of systems that when they fail enter a safe state. Another example is the use of procedures by operators. If operators do not follow procedures they are considered unreliable, but if the procedures turn out to be unsafe under certain circumstances, this behaviour may be the very thing that prevents an incident. Furthermore, the extent to which operators can make these adaptations depends on system design, i.e. numerous situational factors and systemic properties.

Keller & Modarres (2005) bring up another example from NASA operations in the 1980's showing that risk analysis is also affected by its organisational context. It is well known that the launch of the space shuttle Challenger was opposed by engineers from Morton Thiokol, the company which had built the booster rocket that eventually exploded and led to the loss of the spacecraft in 1986. However, as early as 1983, US Air Force engineers performed a fault tree analysis showing that the chance of a booster rocket explosion was as high as 1 in 35, a result which was wildly contested and suppressed by NASA management. This is an example where productive pressures affect the adaptive capacity of a socio-technical system.

What can be learned from these examples is that within a socio-technical system, every component has its context. This context may have several dimensions, be it technical, social, psychological or organisational, and each of them may help or hinder adaptations to threats and opportunities. While the engineering community has spent many years trying to measure and increase the reliability of isolated components, not nearly as much attention has been given socio-technical system interaction, and paradoxically, this is precisely where the causes of many of the great industrial disasters of our time can be found. This perspective on industrial operations is deeply rooted in cognitive science, which has been evolving in a similar, systems oriented direction. While early on, human cognition was considered to be primarily a process of the mind, much focus has later been directed to cognition "in the wild" (Hutchins, 1995), i.e. cognition as a context-sensitive process which is distributed over people and their tools. This perspective provides some answers to how we can support CI adaptive capacities beyond predefined scenarios and increase system resilience. It could be claimed that most professional work has a large cognitive, collaborative component and involves continuous adaptation to the work context. If work is viewed as a cognitive process of constant re-interpretation and action, then adaptive capacities are reached by creating work environments that allow for situation awareness, collaboration, communication, problem-solving and the production of rich experience. From the perspective of the safety science community, focusing on human thought processes is essential to understand how a system can act resiliently.

4.2 Resilience from a systems perspective

Both the IMPROVER lexicon (D1.2) and the IMPROVER international survey (D1.1) bring up several definitions of the concept of resilience, definitions that in turn are associated with different models and assumptions around how resilience should be supported. Applying a systems perspective on industrial operations, however, puts a different light on these definitions. One classification of

definitions based on systems thinking is offered by Woods (2015), who identifies four general groups. First, resilience can be defined in terms how a system *rebounds* to normal after a disturbance. Second, resilience is sometimes used as an equivalent to *robustness*. Third, resilience can be described as overcoming the risk of sudden failure when the system is pushed beyond its capacities. This is described by Woods as a kind of *graceful extensibility* or extra adaptive capacity in the face of surprise events. The fourth definition stems from systems research and describes resilience as a *sustained adaptability*, the ability to continue to adapt as circumstances evolve.

Rebound is a common way of defining resilience in the literature, something that is also reflected in the IMPROVER international survey and by, for example, the resilience triangle (Bruneau & et al, 2003). However, the idea of rebound has certain implications that may cause problems when related to system resilience. First, it is common for rebound-oriented resilience research to primarily consider specific disturbances and safeguard against them, whereas surprise incidents are left out. Second, the notion that the system has some sort of equilibrium that it returns to after a disturbance is contested by the literature. Adapting to disruptions changes a system, and an inability to change may leave the system vulnerable and ineffective. Trying to conserve the system and define some sort of ideal state to return to may therefore lower its resilience in the face of future threats. This criticism of resilience as rebound is to some extent parallel to the notion of "bounce-forward" addressed in the IMPROVER international survey. If we want to describe a system as resilient in the face of a disturbance, however, some aspects of the system must remain unchanged while others change (Lundberg & Johansson, 2015) . Lundberg and Johansson argue that this should be described as a system identity or certain "core goals" which are more or less static, whereas sub-goals and the processes that work to fulfil the core goals may change. While the system could be said to rebound to core goals, the resilience of the system is rather a question of being sensitive to new ways of achieving those goals.

Resilience as robustness shares some of the problems of *resilience as rebound*. A number of issues that were mentioned previously with reference to Leveson and Woods, makes similar remarks. Increasing robustness within a system means increasing the set of disturbances that the system can respond to. This means that robust control only works for disturbances that are well-modelled. However, all systems in natural settings have to handle both positive and negative surprise events where there is no model to guide behaviour. This again should trigger adaptation in the form of re-modelling the system's response capacity. It could be questioned whether events that are well-modeled can really be said to challenge system resilience, which would imply that resilience is really a capacity *beyond* robustness. A brittle system will collapse at the edge of its capacity, while others may extend capabilities to also handle some unexpected events. Furthermore, resilience could also be challenged by optimisation towards certain scenarios. No system has endless resources, so that if optimisations are made toward certain threats, chances are that the system will become more vulnerable to others.

Resilience as graceful extensibility deals with systems that are not brittle at the edge of their capacity but can stretch to handle surprises. To be able to extend its capacity, a system needs to anticipate changes and adapt to them. An important aspect of this is the ability to learn from past events. Since not all changes can be foreseen, however, the system must also build capabilities that are not scenario-specific but can be used to handle unexpected events.

Whereas graceful extensibility is about the operational properties that allow for this kind of extension, *resilience as sustained adaptability* has to do with system architectures and design principles that allow the system to constantly produce new adaptive capacities over an extended period of time, that is, how do we make sure that the system can continue to extend to new challenges in the future.

4.3 The temporal dimension of resilience

As the previous overview shows, the concept of resilience is almost always defined in relation to some sort of disturbance or stress that threatens the system's existence, functioning or survival (Bergström & Dekker, 2014) and because of that, it has been common to describe resilience in terms of different phases on a time-line. Some examples of temporal models are given in the IMPROVER international

survey, such as mitigation/response/recovery and the learning stressed in the fields of social-ecological and disaster resilience. Lundberg and Johansson (2015) track this family of models back to Neisser's (1976) perceptual cycle of perception-understanding-action and similar temporal models are also found in the safety and crisis management sciences. For example, Hollnagel et al (Woods, Leveson, & Hollnagel, 2012) refers to the cognitive processes of anticipating, monitoring, responding and learning as the cornerstones of resilience. In this model, anticipation is perhaps the most crucial component and largely decides the success of other functions. Anticipation makes the system resilient by allowing it to strengthen its defences, but most importantly, this is achieved by constantly re-assessing threats and revising its means of response, something that can minimise the need for flexibility during response. This description follows a vein of research also cited in the IMPROVER international survey (D1.1) arguing that resilient organisations assume that their models of risk need to be updated constantly, that their countermeasures are incomplete and that their grasp on safe operations is fragile. Based on anticipation operators decide what should be monitored for and creates different modes of response. Monitoring supports resilience through the detection of events and through deployment of prepared means, sometimes making it possible to avoid a threat completely. Response is also a feed-forward function, because the operators' actions allow them to understand more about their environment and the problem at hand. During response, resilience may be demonstrated through an ability to improvise and adjust the use of resources at hand. Learning is a pre-requisite for adjusting functions for event detection and modes of operation, focusing the attention of monitoring functions. Although learning should ideally be a continuous function, in many real situations learning is often a consequence of major disturbances. Finally, recovery does not only imply a bounce-back to previous abilities, but may also include the creation of new abilities, fulfilling new goals. This presupposes both the realisation that change is needed and a willingness to change (Lundberg & Johansson, 2015).

4.4 Tentative discussion

This chapter will summarise the findings from the literature reviews and outline what interpretations of resilience are the most worthwhile to pursue in the search for organisational resilience indicators.

Several fields of research continue to show a great interest in the concept of resilience, but its advances has also spurred some criticism, some of which may be relevant for the aims of IMPROVER. As with any metaphor used in science, resilience invites to many interpretations, even to the extent that some researchers fear that the term might be rendered meaningless (Lundberg & Johansson, 2015). The introduction of a concept such as resilience does not in itself signify scientific progress (Bergström, van Winsen, & Henriqson, 2015). In order for resilience not to become a self-contained discipline it is important to preserve its multi-disciplinary origin (Righi, Saurin, & Wachs, 2015) and continue to examine resilient capabilities from many different perspectives, a point that will be returned to in this discussion. However, Righi et al also point out that because certain interpretations of resilience question existing paradigms (e.g. with regard to how safety is achieved), it is likely that its implementation will sometimes be met with resistance. It is a challenge for researchers as well as practitioners to find the definition of resilience that has the largest bearing on current issues in their respective domains and that enables the creation of new knowledge, not one that simply reiterates established safety concepts.

4.4.1 On the premise of complexity

Research both in economy, ecology and safety cites complexity as one of the driving forces behind the need for systems resilience. However, complexity is a concept that can be understood in many ways and where different interpretations have different consequences. One typology for complexity is suggested by Musès (2000). In his definition, Complexity I refers to the complexity that is an inherent part of reality, the nature of our world that resists the full predictability of determinism. In this world so many events, states and processes exist that their combinatory effects cannot be calculated. This realisation is exactly what justifies the call for adaptability in systems. Because total predictability will never exist, it will never be possible to make full descriptions of operations using standards and procedures. Humans fill this gap with their ability to use their experience, to improvise and to make decisions based on incomplete information, described in the literature as *coping with complexity* (Erik Hollnagel, 2012). This is the construction and reconstruction of situation awareness also referenced in the IMPROVER international survey (D1.1). In this context, a gap between research and management theory has been identified (Lissack, 1999). Management philosophies are often based on notions of objectivity and linearity, i.e. the idea that work can be decomposed into neat segments and controlled in detail. This is matched by scenario-based risk assessment where it is presupposed that all risks can be identified and controlled in advance. Complexity I, on the other hand, describes a world where it is often impossible to predict how people should act. To reinforce resilience with regard to Complexity I, the organisation could examine how dependent it is on procedures in operations, what improvement strategies exist beyond risk analysis, how risk analysis is implemented and how the organisation treats its results, how the socio-technical system performs in novel situations and to what extent it supports the creative and adaptive capabilities of the people working in it.

As a contrast to the natural complexity of Complexity I, Complexity II deals with cases of over-complication caused by a lack of insight into the problem at hand, in other words, complexity which is man-made. Everything that we surround ourselves with at the workplace is the result of design, be it tangible objects such as physical interfaces, tools and signs or intangible constructs such as work practices, processes and procedures. These artefacts may differ, however, in how consciously they were designed. In industrial settings workplace design is often governed by laws and guidelines, but while it is fairly easy to prescribe workplace characteristics that align with physical ergonomics, regulation most often gives little guidance on how to support cognitive ergonomics i.e. collaborative, cognitive activities such as problem identification, analysis and planning. A partial cause for this could be that the process of designing a user-centred workplace is intimately tied to a particular work context and thus it is difficult to make detailed recommendations that are valid for a broad range of situations.

Nonetheless, workplace design commonly evolves in a gradual and quite erratic fashion, spurred by technological shifts, re-organisations or competing purposes, without any real guidance or sensitivity to the needs of its users. Consequently, these workplaces may undermine cognitive abilities and cause confusion and problems in collaboration. In turn, this may create serious problems with both safety and efficiency, inhibiting the system's resilient capability. It has been common in the past for the industry to force people to compensate for flawed system designs through measures such as procedures and increased training, leaving the more fundamental design problem out of the equation (Erik Hollnagel, 2012). To allow people to reach their full capacity and to enable quick and creative action, however, organisations must pay closer attention to human needs. When workplaces are created from scratch it is easier to steer design in a user-centred direction, because later corrections of a sub-optimal workplace are often costly and impractical (Donahue, Usability, Weinschenk, & Nowicki, 1999). On the other hand, operations seldom start from scratch (Moorkamp et al., 2014). Therefore, a more important precondition for resilient performance may be that the organisation has a user-centred process of continuous change.

4.4.2 On competing definitions

The IMPROVER international survey presents a number of definitions of resilience and the fact that the term resilience is used in many and sometimes conflicting ways has been noted by several researchers (Bergström et al., 2015; Bourbeau, 2013; Kolar, 2011; Norris, Stevens, Pfefferbaum, Wyche, & Pfefferbaum, 2007; Woods, 2015). In chapter 4, reference was made to the work of Woods (2015) who has suggested a typology of different interpretations of the resilience concept. The following sections will discuss the implications of this typology for the task of D4.3, in an attempt to see what definitions appear the most promising in the search for new ways of developing the resilient capabilities of CI systems.

4.4.2.1 Rebound

Physical rebound after some sort of stress, such as the rebound of a piece of flexible steel, is commonly used as a metaphor for overall resilience in socio-technical systems, although this interpretation of resilience primarily appears to dominate in the world of technical engineering (e.g. under the heading of "engineering resilience" (D2.2). As mentioned in previous chapters, however, this metaphor has been the target of criticism from researchers representing a number of disciplines.

First, sticking too tightly to the temporal dimension of resilience, as in the example of the resilience triangle (D2.2), may introduce a bias towards the operational phase of handling disturbances. This is for example evident in citations describing resilience in terms of "resistance, absorption, and restoration" (D2.2). Both the IMPROVER international survey and other sources note that most discussions about response eventually dissolve into issues of preparedness. Furthermore, many activities during ordinary work are not explicitly connected to crisis situations, but nevertheless contribute greatly to system resilience i.e. the system's capability of handling surprises. It seems unlikely that a system which does not display resilient performance in daily operations will perform resiliently during a crisis. In CI, operational states often intermix so that for example normal operations, maintenance and varying degrees of disturbances are experienced simultaneously. To understand an organisation's resilient capabilities, normal work has to be studied, and this should be reflected in the empirical work of the current report. Nevertheless, since resilience is always defined in relation to some sort of disturbance or opportunity, any analysis of resilience will also have to pay attention to operational phases such as response and recovery.

Second, what is stressed in models such as the resilience triangle (D2.2) is the speed of rebound. This is evident in several citations in the IMPROVER international survey, where resilience is largely defined as the speed of return to an equilibrium. However, these definitions have implications that could be problematic. An organisation which only seeks the quickest possible way of resuming production is likely to make trade-offs so that although production is continued rapidly, safety objectives and long-term sustainability may be compromised. Therefore, even though production is

obviously central for CI, such a one-sided emphasis on the time scale may actually undermine overall system resilience. In this way, speed of rebound, or rather the prioritisation of that speed, could in some cases be a negative indicator of system resilience. When gathering data for this report, it may instead be motivated to examine how organisations deal with these trade-offs between competing goals, efficiency and thoroughness.

4.4.2.2 Robustness

Some of the criticism against resilience as robustness is similar to that against the notion of rebound. In the literature, robustness is commonly associated with technological interpretations of resilience such as "engineering resilience" (D1.1) and denotes a kind of strength or ability to withstand a given level of stress or demand without deteriorating. Resilience is however not simply about being able to resist a shock and return to a previous equilibrium. Rather, it is a question of learning from these shocks and adapting accordingly. Furthermore, it is hard to talk about technical robustness without taking the organisational backdrop into account. It is within the organisation that policies for technical design are set and where issues such as maintenance strategies are addressed. Few industries simply opt for the highest-spec (i.e. most expensive) components at every occasion. Instead, systems design is often a matter of trade-offs involving an organisational discourse over how safety and efficiency is achieved (Erik Hollnagel, 2009). From the criticism it seems that technical robustness could be described as a necessary but not sufficient feature for socio-technical system resilience. Robust technology that degrades gracefully may give people more room to act in a critical situation, but robustness in itself does not necessarily say anything about the resilience of the whole system. Furthermore, more complex behavioural patterns in technology such as graceful degradation will increase demands on its user interface, something that may instead undermine resilient performance if not handled correctly. Technical features such as robustness, redundancy or diversification have already been studied extensively and have seen a wide-spread implementation in CI for decades. When introducing a new concept such as resilience it is motivated to look for gaps to fill in current operational and corporate strategies. This discussion around robustness brings out a number of such gaps such as learning from events and processes for requirements analysis, e.g. with respect to contextual/systemic factors and usability.

4.4.2.3 Adaptation

When definitions of resilience in terms of rebound or robustness are examined, both routes lead into discussions around system adaptive capacity. The need for resilience in critical infrastructure has developed because the context of CI operations is becoming more and more complex, with increasing computerisation and larger organisations with more inter-organisational dependencies. Much progress can be made by applying a systems perspective when developing an organisation's ability to anticipate and monitor for future changes. It is stressed both in the IMPROVER international survey (D1.1) and in related research (Lundberg & Johansson, 2015; Woods, 2015) that resilience is not found in individual adaptations to specific events, but in a maintained capacity for learning and adaptation. As noted in the literature (D1.1), this adaptive capacity must extend over both threats and opportunities, because the success of the organisation will depend on the ability to handle both.

Some notes can be made of what enables this learning and adaptation in an organisation, that is, possible indicators for organisational resilience. The question of what supports peoples' ability to engage in a constant reassessment of operations and to anticipate future variations has many answers, some of which have been condensed from the literature and described in the following sections. Increasing an organisation's ability to anticipate and monitor for future changes is however not the only challenge when resilience is sought, because there is no way of foreseeing every possible disturbance. Therefore the organisation must also prepare for the unexpected. Several of the factors described below affect people's general ability to work effectively, corresponding to the "general abilities" that produce resilience in the face of surprise. It should also be pointed out that while many of these findings are gathered from the safety research community, they can be argued to do as much for work efficiency as they do for resilience and safety.

One set of indicators for organisational resilience has to do with the organisation's understanding of possible risks and opportunities. Because risks in complex environments are diverse, the work to identify them should engage people from a diverse range of organisational levels and functions, representing different, complementary perspectives. These people need to have a broad experience and should be allowed to develop their knowledge through discussions about risks and other changes. In order to fuel discussions around risks, participants should have an understanding of organisational dynamics, e.g. how they are affected by their organisational context and how they affect others, such as other organisational functions. If many voices are to be heard, a certain openness within the organisation (Saurin, Righi, & Henriqson, 2013) is demanded, so that opinions from all organisational levels are acknowledged. Professional work should also cater for a high level of vigilance, e.g. by avoiding monotonous tasks and tight proceduralisation. A person's ability to process and make sense of information is also dependent on a work environment and tools that have been designed according to her needs, or rather, the needs of the socio-technical system. The same collaboration that should be seen in risk analysis should also be present in everyday work, so that the collaborative ties demanded in a crisis situation are continuously reinforced. Once a risk is identified, however, people also need to have the room to act. This may not be allowed by a traditional, strict organisational hierarchy based on top-down management (Dekker, 2003). Allowing for local action is both a question of creating a certain autonomy and the right organisational structures and processes to facilitate this.

On a management level, these features are supported by activities where operations and outcomes are discussed during every day work. Training programs need to be based on sufficient realism mirroring the complexity of real-world operations. As far as design is concerned, the design of organisational structures, processes, work environments, tools and other technology should be produced in a design cycle firmly rooted in analyses of use. From the resilience perspective it will also be a challenge for designers to find the requisite amount of flexibility for these organisational elements, so that they lend themselves to a variety of user needs.

On the other hand, in some cases people's ability to adapt may obscure organisational or technical deficiencies. It is also conceivable that the adaptations of one organisational function could come in conflict with the activities of others, so that local adaptation becomes sub-optimal. On the same note, while procedures may limit the requisite imagination of their users (Westrum, 2014) they also provide stability and common ground, something that implies a trade-off situation (Lundberg & Johansson, 2015). As noted both in the IMPROVER international survey and elsewhere (e.g. Moorkamp et al., 2014), wide-spread adaptations may introduce chaos and make the organisation too dependent on external forces. A system that is constantly employing its resilient abilities either works in an extremely low-predictability environment or has insufficient structures to support learning from experience. It could even be argued that a certain organisational inertia could prevent the organisation from making adjustments based on weak or false information. Furthermore, no system has endless resources, and it is probably difficult for a system to uphold the same level of preparedness for both common and uncommon challenges. To resolve conflicts like these and make better trade-offs, management has to have a direct insight into actual working conditions and work closely with practitioners, bridging the gap between work as imagined and work as done (Antonsen, Almklov, & Fenstad, 2008). As a final note, all of these organisational features may be meaningless if management does not also take steps to support a culture where expertise, respect and an open dialogue are valued, toning down the emphasis on procedures in favour of risk consciousness and professionalism.

4.4.3 On the deconstruction of system resilience

The IMPROVER report for D2.2 suggests a division of resilience into societal, organisational, technological domains. In order for the results of a resilience analysis to be practically applicable, some sort of division or boundary for the analysis is necessary. However, the present division seems to be made more between research disciplines than between practically useable domains. It is true that research on resilience calls on many disciplines, but more so, it calls for the collaboration between disciplines. This is because resilience is primarily defined as a system property, not a component property. In a system, no single actor guarantees emergent resilience, but all actors influence resilience

through their actions, relations and interactions (Bergström & Dekker, 2014). This idea is in line with research cited in the IMPROVER international survey (D1.1), where organisational resilience is described as the capacity of the people and systems that facilitate organisational performance to maintain functional relationships in the presence of a disturbance, a definition that also brings out the importance of interactions for resilience. Cross-organisational interdependency was also a popular theme during the 2016 IMPROVER operators' workshop in Ispra, Italy, although intra-organisational/system interactions were not given the same attention.

Drawing a line between organisational and societal resilience can be defended to some extent because that corresponds to widening circles of systems within systems, although drawing a system boundary like this will always be an analytical sacrifice (Bergström & Dekker, 2014). Technological resilience, on the other hand, does not hold the same correspondence to the other categories.

This discussion brings out the difference between the functioning and roles of people and technology in socio-technical systems. Robust technology may allow components or technical system to fail more gracefully, but that does not necessarily say anything about the whole system's ability to continue operations in a controlled manner. It can also be noted that while technological advances may support resilient performance, they may also introduce more system complexity and new risks. While technology will fail beyond pre-defined scenarios, human cognition allows for our capacities to stretch under pressure. This ability to interpret information, collaborate, act and adapt is distributed over people and technology, and it is precisely the abilities that enable resilience in the face of surprise. Resilience in the face of disturbances is fundamentally a human capacity and demands that people can collaborate well, are given a good chance of understanding the situation and have the freedom, competence and ability to act creatively when that is needed. It is clear from the current work on "technological resilience" within IMPROVER (D2.2) that this concept is primarily associated with the properties of technical components or constructions, described as "an engineering point of view" on resilience. Here it is envisioned that resilience will be "achieved by technological rather than organisational solutions", seemingly paying little attention to the place of technology in the overall socio-technical system. However, this obscures many other potential functions of technology for overall resilience. Facilitating the work of people should be the first priority when trying to improve CI resilience. While features such as technical redundancy and diversification are important for the system, they do not represent something new in the discourse of CI operations.

A suggestion might instead be to focus on the extent to which technology lends itself to human activities and system interactions. For example, it has been noted earlier that human problem solving can be greatly helped by the right contextual support, e.g. user centred designs in the work environment and supporting technology. Since adaptability is often mentioned as a core feature of a resilient system, it may be interesting to investigate technology that lends itself to many different uses, answering many possible user needs. Most technology has some sort of an interface towards human users, even if the purpose of the interface (e.g. maintenance) is not directly related to system control. Focusing on user needs is, however, far from standard in CI systems design, which means that improving human-technology interactions should present many opportunities to strengthen system resilience. Studying these system interactions will be essential to understand how people can be supported in their adaptive activities. On an organisational level, this can be realised through design policies and processes that enable continuous improvements.

4.5 Outline of organisational resilience

Based on the literature review, an outline of factors contributing to or signifying organisational resilience was developed.

Organisational resilience is the ability of an organisation to…

- Constantly re-assess itself and the situation using a diverse set of skills and knowledge
- Engage all parts of the organisation in idea generation and problem-solving
- Adapt and re-invent itself when faced with unexpected events
- Build the right support for sensemaking and action based on a profound understanding of practical working conditions
- Make decisions based on a firm understanding of real-world operations, the current situation and the need for trade-offs
- Collaborate in a dynamic networks of actors
- Stay humble in relation to the predictability of real-world operations

5 Case study analyses

This chapter presents the results of analyses of four different cases.

5.1 Case descriptions

Two living labs were analysed, the Öresund region and the fresh water supply in Barriero, Portugal.

5.1.1 Case 1 - Increased volumes of refugees in the Öresund region 2015

Throughout 2015, but especially in the autumn, immigration flows to Sweden increased to the highest levels since Second World War. Refugees arrived to Denmark via the German border, some sought asylum in Denmark, but many travelled on to Sweden by train over the Öresund bridge. Refugees also travelled between Germany and Sweden by boat. Some of them had Sweden or Denmark as their final destination, and some travelled on further to Norway or Finland. Infrastructure in especially the southern part of Sweden, but later whole Sweden, experienced stress and transformed to crisis management. Lots of different organisations were involved; governmental agencies, police forces, municipalities, technological infrastructure operators and NGOs.

The flow of immigrants to especially Sweden in the Öresund region, started to increase during late spring and summer and in the beginning of September it reached significant levels. First in retrospect was it possible for involved actors to identify the significant raise in refugee flows and many informants say that it was impossible to predict and that they were taken by surprise. This since fluctuations are expected, viewed as normal and the flow increased to non-expected levels in just days. Several informants say that pictures of Alan Kurdi, the Syrian child washed ashore dead on a beach in Turkey on his and his family's way to Greece, started a movement in Sweden. Volunteers engaged in different ways to help refugees directly and/or via governmental agencies. In October the amount of asylum seekers in Sweden doubled compared to the month before. In November, with reference to the distribution of refugees across the European union being unfair, the Swedish government decided to initiate border controls, which led to all refugees reaching Swedish land were forced to seek for asylum. All refugees, even those who just wanted to pass through Sweden, now were led off at the first train station in Sweden, Hyllie, and taken to the refugee arrival center and queues became long. The local authorities were even more stressed because of the redistribution of flows and increased amount of people that had to be taken care of the formal way. Before, NGOs relieved the pressure on mainly the Migration Agency and Malmö municipality by offering accommodation and food. The border controls and refugee restrictions increased in phases during the rest of 2015 and January 4th 2016, Sweden introduced ID checks before travel to Sweden (on the Danish side of the Öresund bridge) combined with the remaining border controls.

In interviews we are using the case to talk to the informant about organisational prerequisites in the organisation they belong to, regarding resilient abilities. This since the refugee flows were unexpected, led to a stress on most organisations and led to crisis mood. Resilience isn't operationalised in most organisations, so we couldn't ask direct questions about this. We had to ask other questions, analyse the whole body of empirics and map it towards themes. The purpose with the interviews were never analysing the case itself, just using it to find resilient abilities and success factors on an organisational level.

5.1.2 Barreiro fresh water supply

5.1.2.1 Case 2 – Water tower of Alto da Paiva runs out of water

During the planned cleaning operation of the Water tower of Alto da Paiva, Hospital Centre of Barreiro Montijo, problems were observed related to the lack of pressure and/or interruption of water supply to the hospital, as well as to the parish of Lavradio (except for Quinta dos Fidalguinhos) and part of the parish of Barreiro - Bairro das Palmeiras. In total this meant the affection of 12 thousand

inhabitants and one of the main hospitals of the district, which serves the counties of Barreiro, Moita, Montijo and Alcochete.

This event took place during the cleaning operation of the Alto da Paiva reservoir, a procedure that is carried out every two years. Both the affected population and the hospital administration were informed about this scheduled intervention through direct communication. The hospital has its own reserves of around 300m3 of water and they were supposed to impose restrictions on consumption, especifically with respect to cleaning floors and pavements, the irrigation systems, etc, so that with these reserves the hospital could withstand the period of interruption/reduction of the water supply.

However, due to lack of internal communication from the hospital administration to the responsible technicians, nothing was done in terms of consumption restrictions. On the cleaning day the administration of the hospital reported that they were left without water. This was an extremely complicated situation because emergency care and the operating rooms were full of people.

Contacts were made to ask the cleaning company to speed up the intervention, and the intervention was completed about one hour later. Then all the water catchment systems were used to fill the water tower reservoir.

At the same time, the fire department was negotiated to help fill the hospital's reserves until the main system was fully operational. In the municipality of Barreiro there are 2 fire brigades, and given the rate of hospital consumption and the size of the reservoirs versus capacity of the tankers of the corporations, it was decided at once to request the collaboration of the district rescue operations and civil protection commands, as they were able to receive the support of from more brigades in the district, meeting the current hospital needs. A total of 14 fire brigades from the District of Setubal were engaged for this intervention, all of them with auto-tanks, which they supplied in the network, in order to supply the hospital reserves later on.

5.1.2.2 Case 3 - Hydrocarbon detection in the results of routine water quality control analyses

The local authority was informed by the laboratory that took samples of water on Thursday evening, the eve of a national holiday, that the analytical results showed the presence of polycyclic aromatic hydrocarbons (PAHs) in the water for public consumption. This situation led to the immediate deployment of confirmation analyses and communication to the population not to consume water from the public network until further notice. Water catchments in Coina were stopped because they were showing, for some time, lower water quality (although within the admissible parameters, which was not related to the "hydrocarbons" parameter).

Verification analyses of possible non-compliances were carried out in the laboratory responsible for routine monitoring. The tests continued indicating the presence of hydrocarbons in the samples from various sites of the supply system. Further analyses were carried out in other laboratories, some of them inconclusive, which required even further analysis and getting in touch with the Ministry of Environment – an ultimate authority responsible for managing water quality control issues. On the following Saturday the results of the verification analyses came in. It was concluded that the values initially obtained were due to a laboratory error and that there was no any emergency in the water for public consumption in the municipality of Barreiro.

5.1.2.3 Case 4 – Company in insolvency leads to abandoned dangerous goods

On January 14, 2010 the Municipal Civil Protection Service was notified that the company CPB (Companhia Petroquímica do Barreiro) was insolvent, through a telephone contact with the law office that managed the CPB insolvency. This company operated a chemical processing facility at the Bay of Tejo, which was now abandoned totally without security and electricity. Shortly after abandonment the facility was vandalised.

Contacts were established between the Governor Civil, the Distric Commander and representatives of the Bay of Tejo, the Lawyer's Office managing the bankruptcy, firefighters from the South and Southeast regions and PSP (Polícia de Segurança Pública, Public Security Police). The Barreiro division of PSP was asked to implement all possible measures for monitoring the areas of access to the factory premises. The presence of Setubal firefighters was also requested so that risky conditions could be managed promptly.

Contacts were made with several entities, among which were the National Authority of Civil Protection (ANPC), Portuguese Environment Agency (APA), Inspection General for Environment and Spatial Planning (IGAOT), and Regional Coordination and Development Commission (CCDR). The last two entities deployed their technicians to evaluate the case in situ.

Among the hazardous products identified at the site were about 12.5 tonnes of propylene oxide, a product flammable while contacting with air, and with highly explosive expansion characteristics in the tank and pipes of the manufacturing area. This required the removal of the product, as soon as possible and with maximum safety into a cistern.

Problems arose when contacts were attempted with the Head of the Office of Environmental Emergencies and Risks of APA, who did not respond despite several attempts. This office was contacted to request some additional information on measures that could reduce incidents, such as removing the handles that could easily displace the dangerous products, as some of these products would inflame at contact with the air.

In the face of these difficulties a meeting was requested with the presence of all entities with competence and responsibilities in this matter. A first meeting of the Subgroup on Dangerous Matters was held, where it was decided to consider the area of CPB premises and their surroundings as a high-risk zone, requesting the Authorities of the Baía do Tejo (a local territorial and business park management company) to prohibit access to the area. After these measures it was decided that a session of the Municipal Civil Protection Commission would be organised, which took place on March 30.

On this session it was decided that a meeting would be organised with the various entities that bear responsibilities for the occurrence in accordance to the SEVESO II Directive (Council Directive 96/82/EC of 9 December 1996 on the control of major-accident hazards involving dangerous substances, see https://en.wikipedia.org/wiki/Directive_96/82/EC). The meeting resulted in the creation of a working group involving the Civil Government, the Judicial Manager of CPB (through its representative), the former CPB workers, Repsol, Baía do Tejo, the Municipal Civil Protection Service and the ANPC.

On the basis of the Working Group, an operational team was created comprising Repsol (with Portuguese and Spanish technicians), former employees of CPB, and employees of Baía do Tejo, in order to overcome the technical restrictions of the product containing set-up and to allow the removal of propylene oxide to a safe road cistern, since this could not be done on-site. This team also included representatives of the Civil Governor and the Municipal Civil Protection forces for providing rapid solution of bureaucratic issues or other difficulties that required legal and/or financial procedures.

An unconditional support of the former CPB workers was required for this work, both to identify/locate the products and to quantify them. As well, which is not less important, careful and safe operating of the product containing equipment was a must. For this reason, 3 shift chiefs and 3 workers were selected for carrying out the task on the basis of their profound knowledge of the facilities.

On May 18, emergency set-ups were deployed by the ANPC to respond to a possible emergency situation, and then the transfer of propylene oxide to the road cistern began. The operation proceeded without incidents and, at about 12 pm the tank started its return trip to the Repsol facilities in

Puertollano, Spain — with about 12,500 kilograms of propylene oxide, escorted until the exit of the A39 highway by the police forces (PSP).

The process that took place at CPB premises was never used or even tried at any other similar installation anywhere, at least to the best of the informant's knowledge.

5.2 Results of analyses

Results of the analysis are presented under themes that evolved under the thematic analysis and which also serve as section headings in this chapter. The analytical themes were

1. Design of tasks and roles
2. Artefact design: goals, rules, processes and procedures
3. Strengthening collaboration
4. Facilitating learning and re-design
5. Underlying values and interpretations

Within each theme the empirical data from interviews are analysed and related to the theoretical framework. The themes represent areas where key aspects of organisational resilient performance were identified.

5.2.1 Design of tasks and roles

When asked to point out organisational strengths with regard to personnel, informants representing all cases stressed that experiences from diverse operations facilitate decision-making during demanding circumstances. The same appears to be true for managers, where those who had direct experiences from sharp-end operations seemed to make decision more in alignment with real-world demands and also seemed to be more prone to root their decisions in the workforce. Experience of actual crises are treasured, evident e.g. in the way both governmental and voluntary organisations of case 1 value the individuals who took part in the response to the escalation of immigrants, as well as the relations that were built during those days. From an organisational point of view, the overarching question in connection to this theme is how to support the development of broad experience in a systematic fashion, that is, how to produce rich experiences.

The literature mirrors this focus on learning from experience and using this as a cornerstone of operations. When tasks and roles are designed to engage employees in a constant examination and interpretation of their working environment, they become vigilant and hone their abilities to identify risks and solve problems. The interviews suggest that people whose normal jobs are tightly controlled by processes and procedures find it difficult to adapt to unforeseen circumstances. Letting more people engage in active and flexible everyday problem-solving may also serve to bridge this gap between normal operations and surprising events. If people can obtain a wide range of work experiences, that may also make it easier to match certain operational demands, something that was mentioned during interviews. For example, when an employee is allowed to learn about many aspects of work both within and outside of the organisation, that could facilitate the flexible use of resources e.g. making it easier to see possible different uses or users of resources. This could also something that might make it easier for employees to switch roles.

Some organisations of Case 1 such as the Swedish Armed Forces and the MSB keep tight records on employee skills and experiences and they both show a strong support for the standardisation of functions/roles within the organisation. While this practice is feasible for well-defined skills, it is important to point out that all professional qualities of an individual can never be covered by entrys in a database, something that is confirmed by an informant saying that when an employee is selected for a mission, there is always a large component of personal knowledge. The way in which such records are constructed is also dependent on the organisation's view on knowledge and how knowledge is constructed. This conception is reflected in the work of Gauthereau & Hollnagel (2005) who state that

because actual conditions of work can never be fully predicted, a work task becomes an activity first when it is placed in a real context. When an outside observer attempts to describe the work of others, those descriptions tend to be more linear and standardised than work in real life (E Hollnagel, Nemeth, & Dekker, 2008). A mechanical approach to determining the content of work roles could for example be to prescribe a certain set of mandatory educational courses. An approach more rooted in the resilience literature would be to describe what kinds of professional experiences are necessary to fulfill a certain role. To the benefit of standardised roles, however, such roles could very well help the individual organisational actor to form a clear picture of their purpose in the overall system.

Finally, a major challenge in Case 1 during the days of the immediate escalation of immigration was to compensate for a lack of experience in the new volunteers and temporary employees who flooded both governmental and voluntary organisations. The most common solution to this was to issue down-sized training programs covering both organisational and task knowledge. This, however, borders on a common problem in infrastructure operations. Older, long-time employees often worked their way up through the organisation, building practical experience along the way. When this generation is replaced by new recruits, allowing for the same build-up of experience becomes a major challenge, something that is hard to compensate for through common educational efforts.

5.2.2 Artefact design: goals, rules, processes and procedures

In the process of dealing with the several of the cases, many of the involved organisations made observations around the governance of organisations and work, such as the influx of laws, work procedures and processes.

In Case 1, after the owner of Malmö Central Station detected the first signals of an increasing flow of immigrants, getting the attention of governmental organisations was a slow process. Governmental agencies were asked to contribute to the developing situation at the station but instead referred to their standard procedures, e.g. that immigrants should simply report to the local office of the Migration Agency, even though they had nobody to guide them there. Several supporting and voluntary organisations attest to a relative inertia in governmental agencies.

A temporary holding ground was arranged for newly arrived immigrants (Posthusplatsen, a square right outside the station). People were expected to stay there only for a short time when waiting for buses to take them to the Swedish Migration Agency, but when this process slowed down and people were left sitting there for hours, a strict rule that nobody could go inside the station and sleep in the heated waiting hall was still enforced. Furthermore, the locale did not match the requirements of housing such large volumes of people for an extended period of time. Later during the fall a temporary arrival centre and accommodation opened at Malmömässan, a hall complex for exhibitions and fairs. However, because of fire restrictions mattresses were not allowed and people were forced to sleep on cardboard sheets, and because these locales were initially meant for very temporary housing, many other resources such as toilets, showers and health care were scarce. In this situation no organisation could find ways to set aside detailed regulations in order to solve an emergent problem and improve the conditions for immigrants.

In some cases described by the informants of Case 1, economical constraints of organisations or governmental institutions hindered resilient action, e.g. in the acquirement of physical resources or in connection to voluntary activities. In one such example, the organisation Kontrapunkt, which during the event arranged housing for large number of immigrants, was later disqualified from further governmental subsidies, with the argument that they had been running a shelter for immigrants instead of the cultural activities that had been specified at the time of application (half a year before the refugee situation). In other examples, the Civil Contingencies Agency stepped in and paid for transports when other governmental institutions were restricted, something that served to speed up the processing of immigrants. It is clear that economical structures and constraints can play a large role in allowing or hindering resilient action in the case of events that fall outside of planned-for scenarios.

At the same time, there are also examples where governmental institutions acted in a flexible manner. This is evident in the downscaling of ordinary processes within the Migration Agency and Malmö municipality, or in the sentiment of one governmental employee in Case 3 saying that since it was assumed by all that the situation was extraordinary, routines had to be approached with much scepticism. In these events, trade-offs have been made by people close to actual operations who have been able to see and compensate as far as possible for negative side-effects.

Comparing all the different organisations involved in Case 1, it appears that those who had clear organisational goals found it easier to adapt and look for new ways of fulfilling them. Some examples are the voluntary organisations of Case 1 which are driven by humanitarian causes, simply looking for ways to fulfil basic human needs, or Öresund Bridge whose main objectives it is to keep the bridge over Öresund open and maintaining the flow of traffic. In the case of governmental institutions such as the Swedish Migration Agency or Malmö municipality however, their operations were influenced by political decisions and budget constraints, and informants report of a constant flow of new and often conflicting directives. According to one informant, In Denmark different factors, such as a negative opinion towards immigration and a fundamental inability within the governmental agencies to handle the situation, led to a near-total surrender to the situation, where immigrants were simply directed onwards to Sweden. Similar notes are made around Case 4, where examples can be found of both corporations and governmental organisations whose contributions were hindered or much delayed by legislative or economical obstacles, in one instance described as a kind of "apathy". This informant points to a gap between legislation and the challenges of real-world operations to explain some of the institutional inertia apparent in that case. In total, these organisations were not as quick to adapt their goals and means to the practicalities of the situation.

In the future, a likely challenge for governmental organisations will be to find ways of detecting when established rules and procedures are no longer appropriate and adjusting them based on information from the field. In Case 4, the Civil Governor and the Municipal Civil Protection Forces were involved precisely with the aim of providing rapid solutions to bureaucratic issues. As noted by an informant, the process of chemical removal at the site was never used or even tried at any other similar installation anywhere, which demanded extraordinary measures. Trade-offs like these is a balancing act however, because in many cases, established procedures provide stability and predictable results. If these procedures are questioned first in the event of a major crisis then the organisation will likely be too unaccustomed to these kinds of trade-offs. Instead, it may be more effective to build this type of questioning of entrenched habits into everyday operations, empowering front-line workers to critically compare procedures with the reality of operations. In several of the organisations that made these adaptations successfully, changes were made in relation to clearly defined and deeply rooted core values. One way of approaching the issue may be to look for these core values or core functions which are necessary for operations under any circumstances.

While governmental agencies seem to have been tied down by strict regulations in several of the cases, there are also many examples where voluntary organisations could fill the gap. In Case 1, when regulations disallowed Malmö municipality to distribute food at Posthusplatsen square, the Swedish Red Cross could step in. When the policies of the migration agency made it impossible for them to deal with immigrants who did not want to seek asylum in Sweden, the voluntary organisation Kontrapunkt arranged housing for 100-500 persons at a time. This image, however, is not confirmed by the agencies, who claim that so called autonomous organisations obstructed their work in dealing with the immigrants. Indeed, there are also examples where the actions of voluntary organisations may have been counter-productive for the individual immigrant or where resources were not optimally distributed. At the same time, many informants testify to the massive willpower behind the voluntary contributions. As pointed out by one informant in Case 2, voluntary organisations can often complement the action of official institutions, because their knowledge of the particular location, the facilities, the population range covered etc. allows them to function as an important link or communication chain. These findings suggests that voluntary activities will always be present during a crisis and that not all of them will be under governmental control, which means that governmental

organisations must find some way of utilising their potential or learning from their ability to act quickly and adaptively.

The relation between operations and regulations also reflects on the use of plans and procedures for the purpose of organisational resilience. Many of the contributing organisations have worked to build new contingency plans after the event, but as noted by several informants, these plans must also be made into "living" artefacts, e.g. that there is a constant discussion around their contents and that they are frequently tested in use or simulations. Furthermore, an informant from the Swedish Civil Contingencies Agency notes that plans such as these can work to undermine organisational flexibility and as mentioned in the literature review, real-life events always call for an adaptability beyond pre-described scenarios. One informant in Case 4 points out that while it is demanded of organisations that they should have these kinds of plans, in reality they are scarcely realised. Instead their practical function may be to demonstrate organisational compliance, and even simulations can be seen as a play performed by a group of trained actors if they do not incorporate unforeseen scenarios. Furthermore, organisations that are hierarchical and built on the principle of command and control have been observed to be less flexible in the face of a disaster (D1.1). There have been several attempts in developing support for emergency response and crisis response. One reason for many of these failing, is a lack of understanding of real work problem-solving and involvement of end users in the process (Norros et al., 2009).

It is a challenge for organisations to make plans and instructions that do not hinder this adaptability, that give room for practical knowledge and that are adapted to the needs of its users, utilising the experience of broad layers of employees during its design. These are principles for design that hold true no matter the product of design, be it organisational artefacts or physical tools or environments. In the literature it has been noted that much of the success in modern-day industrial systems is due to the fact that people are good at being flexible and working around badly designed routines and instructions (Dekker, 2003).

5.2.3 Strengthening collaboration

During the interviews, a number of comments were made concerning internal and external collaboration, where such interactions appeared to affect organisational adaptive capabilities. In the literature it is pointed out that due to increasing organisational complexity, understanding interactions is actually a more pressing issue than understanding the internal functioning of system components (Hutchins, 1995).

Comparing the different organisations, it is clear that with larger organisations and with a more hierarchical line-of-command, many issues arose when circumstances changed quickly. In case 1, when managers of refugee shelters at Malmö municipality attempted to use the proper channels for the procurement of goods, administrative delays led to an unworkable situation. In this organisation a central crisis command was also created, but according to the informants, this command centre had no insight into practical working conditions and failed to make helpful decisions. Instead, conflicting decisions and messages led to confusion and further delays. During the whole event, it is reported, no representatives of upper leadership came to form their own view of the situation on the ground. This is reflective of the situation at Malmö Station at the earliest stages of the event, where Jernhusen had to fight hard to get the attention of governmental agencies, let alone get representatives of those agencies to visit the site and make their own assessment. A similar pattern appears to have emerged within the Swedish Migration Agency. When a decision was taken to introduce border controls, the case load at the regional Migration Agency increased dramatically, because immigrants who otherwise would have continued to seek asylum elsewhere were now forced to do it in Malmö. This led to a number of side effects such as long queues at the regional office and the procurement of temporary housing at Malmömässan, where informants report that further interference from Migration Agency central headquarters delayed matters even more. On a similar note, when the regional Migration Agency needed clear decisions, e.g. when the other five Swedish regions of the agency said no to receiving

more immigrants or when things were getting out of hand at the local Malmö office, no real support was given from headquarters.

In many ways, collaboration can be supported by different facets of organisational design described in the literature and in previous chapters. Judging from many examples described by informants, a key factor behind good internal collaboration is a tight joint interface or likeness between those who detect and interpret early signals of change and those who decide about actions. Signals of important changes are often subtle and manifest in the course of sharp-end operations, and if such information is not adhered to, the organisation's response may be delayed. A more direct communication with hospital technicians was mentioned as one of the key aspects of preventing an repetition of the incident in Case 2, and in Case 3, one of the main success factors was good collaboration between top management and operational services. It is also clear that in the organisations that acted the quickest when the situation arose, people working close to operations had or took the mandate to act autonomously, all the while reporting upwards about their actions. In order for an organisation to act resiliently, it appears that delegation must be effective and that there must be efficient structures and practices for communication between organisational layers, with a large component of influence and adaptability from those who are best suited to evaluate the operational situation. It is also clear that higher-level strategic decisions must be based on a thorough understanding of practical conditions and limitations. As noted before, several organisations stress the value of managers with direct operational experience. In Case 1, these persons could for example tell when new personnel did not function in their roles, they were more prone to delegate and when the workload became extreme, they could also carry out operational tasks themselves.

The escalation of immigration into the Öresund region demanded organisations to collaborate with actors of which they had little experience. This observation, that large-scale events often mean that organisations have to work in hastily formed networks and that this makes collaboration a particular challenge has also been noted in research (Lundberg & Johansson, 2015). Difficulties in collaboration was noted e.g. between the Swedish Migration Agency and MSB, voluntary organisations and Malmö municipality. Quite notably, very few informants mention any collaboration with organisations across the Öresund. In the cases were organisations had prior experience of working together, collaboration was smoother. An informant from the Swedish Armed Forces notes that on the whole, Swedish governmental institutions and actors had large amounts of data pointing to an increase in the flow of immigrants. What was missing was an environment where such pieces of information could be brought together and analysed as a whole. In several of the Portugese cases, broad collaboration is singled out as one of the main factors behind success. For example, in Case 4 a number of initial meetings were held to ensure that all necessary parts were involved. Diverse network allows for much flexibility in action and use of resources. However, because there is no way of foreseeing every possible crisis, determining which actors an organisation might have to work with during a crisis is difficult. This appears to demand a certain creativity in mapping out potential collaborators, a process that is likely facilitated if a variety of people from a variety of organisational branches are allowed to contribute.

Furthermore, well-functioning collaboration develops during action, which means that organisations must create ample opportunities to learn from actual collaboration, solving common problems. Formal collaboration without physical interaction can never match the benefits of actually working side-by-side in problem-solving (Koskinen, Pihlanto, & Vanharanta, 2003). Such collaboration allows organisations to learn about the capabilities and resources of other. In case 1, collaboration between MSB and the Swedish Migration Agency, where MSB was to provide support to the Migration Agency, was decided on a very high organisational level, without any real input from the persons who would execute this support. As a result the actual demands of the situation did not match the predefined task when MSB personnel arrived at location. Swedish armed forces, on the other hand, initially sent an investigator in order to formulate the support needs themselves and could then meet these needs in an efficient manner.

In Case 1, a clear difference can also be seen in communications within governmental and voluntary organisations respectively. Voluntary organisations made common use of social media which allowed them to coordinate response activities quickly and to amass large quantities of money and physical resources. By using social media, one of these organisations was also able to make solid predictions about the volumes of arriving refugees, e.g. by talking to similar voluntary organisations in Austria and Germany who could gauge this based on the number of train tickets they issued. This was a major aid in the planning of different response initiatives. Unfortunately, because there were few effective links between governmental agencies and certain voluntary organisations, some of these resources could not be taken care of and utilised by official institutions.

5.2.4 Facilitating learning and re-design

Previous chapters have mentioned how organisational structures and relations affect the ability to gather and utilise a broad range of experiences. On this note, it is interesting to observe how the organisations involved in the different cases have gone about to gather and process observations made during the event. When asked about this, most informants describe how the event has resulted in new plans, procedures, templates and reports. In some instances sharp-end employees have been involved, but this is far from the norm and as mentioned in a previous chapter, this kind of knowledge also need to be alive and actively processed within the organisation. Lessons solely collected from higher hierarchical levels in the organisation are not likely to be representative for the whole organisation and risks leading to the introduction of new structures, plans, procedures or technology designed from a work-as-imagined perspective. This leads to new challenges in reaching work goals, since the work force must sometimes struggle even harder with the new added structures.

In a number of the involved organisations these events are said to have fused people together, and riding on that wave could make it easier to adjust the organisation based on operational experience. A challenge for these organisations may be to extend learning into everyday operations. If the organisation engages in a kind of constant self-interpretation, looking at how close to the boundaries of its capabilities it is operating, constantly re-assessing its goals and means, then this will also make it easier to adapt its capabilities to changes in the environment. A common challenge in organisations, however, is to convert valuable lessons into actual change in organisational structures and practices. Often lessons learned stay at a strictly administrative level, at worst adding another routine on top on the existing ones. These processes could also be problematised further. When analysing any type of event, the analyst often manifests an underlying accident model in the way investigations are carried out (Lundberg, Rollenhagen, & Hollnagel, 2009). The causes found in an event analysis reflect the assumptions of the accident model according to the what-you-look-for-is-what-you-find principle, pointing towards the later chapter on organisational values and interpretations. Furthermore, inherent models in the analysis of events could also relate to hierarchical levels or positions within the organisation, leading to one-sided analyses. For example, a sharp-end worker at the Swedish Migration Agency states that the person’s own perceived success factors from Case 1 have not been considered, evident in the way the agency has carried out several later reorganisations in a short period of time.

Lastly, taking care of lessons learned demands a process for driving organisational change that is based on the analysis of user needs in work-as-done and that contains a large portion of end-user involvement. This, in turn, rests on certain organisational values and conceptions discussed in the previous chapter.

5.2.5 Underlying values and interpretations

Underlying many of the previously mentioned organisational functions are entrenched ways of dealing with challenges, and in some cases it is possible to sense certain core assumptions or beliefs around the functioning of the organisation, human actors and the dynamics between crises and other events. These underlying values affect how organisational aspects are interpreted, understood and managed.

In the chapter about organisational structures and processes it was shown how clinging too hard to established regulations, procedures and processes could have negative consequences for the organisation's adaptive capacity. A few informants openly allude to the complexity of real-world operations. In particular this term has been used to describe large organisations in societal infrastructure which makes it especially relevant in this context (Norros, 2012).With the comment that sometimes "there are no predefined answers" one informant stresses the need for flexibility in all operations, not just during major crises. As a contrast, the Swedish Migration Agency is said by several informants to have been caught up in an administrative culture where little attention was paid to developments outside of established routines, even though the agency itself holds a different position. The acknowledgement of complexity and the necessity of making trade-offs around goals and means appears to be an important facet of the core beliefs of a resilient organisation. A fundamental respect for unexpected situations is likely to shape both organisational design, the way work is carried out and how relations are formed within the organisation, as exemplified in previous chapters.

If surprises are acknowledged it becomes even more important to provide front-line workers with the personal capabilities and organisational support to interpret the situation and act flexibly. In order to accomplish this, an organisation must look at the working situation of employees from a socio-technical perspective, i.e. another fundamental perspective on organisational life. A socio-technical perspective shifts the focus from blaming the individual for errors to looking at the broader context of work. Unlike linear, simple and sequential systems, linkages and dependencies between components in complex systems constantly shift. Complex systems can never be fully described or predicted (Hitchins, 1992; Perrow, 2011). The term socio-technical signifies that the system cannot be isolated to for example engineering design, nor detailed interaction between humans and technology. Relating work to context has proven crucial for understanding the functioning of teams in high-risk situations (Heldal & Antonsen, 2014) and a fundamental principle should be to look at what produces positive outcomes, not only how negative outcomes can be minimised (Antonsen, Skarholt, & Ringstad, 2012). Social and human aspects of the system is so critical that it cannot be disregarded, and in the socio-technical context, humans are a success factor (Dekker, 2014). The ability of employees to act flexibly is governed by their chances of building broad professional experiences, their collaboration with others, their mandate and their physical working environment. To realise this, an organisation must have a fundamental understanding of how good working conditions are built, always starting off from an understanding of user needs when artefacts are changed or new ones introduced (Wilson, 2014).

For an organisation to build conditions like these, there must be a live connection between decision-makers and operations, a small difference between work-as-imagined (WAI) and work-as-done (WAD) (Hollnagel, 2014). Employees at all organisational levels must be seen as valuable sources of information of real work challenges and be allowed to participate directly in critical problem-solving. Through active involvement, trust and transparency is allowed to develop, and it also likely to build a sense of ownership, possibly strengthening the will of employees to contribute to the organisation's goals. This is something that, for Case 1 in particular, is apparent in voluntary organisations but perhaps not always in societal infrastructure. These kinds of inter-organisational contacts are also important to uncover working conditions that are wanting, or external pressures afflicting sharp-end actors.

Leading values like these can be envisioned at many levels – with regard to the core goals of the organisation, or to how those goals are reached. As mentioned before, it is interesting to note that voluntary organisations whose work is guided in a very direct manner by such values found it relatively easy to make decisions and change direction during the event. In several of the Portugese cases in particular, similar "humanist" values, an overarching will to safeguard the population, were referred to.

6 Organisational resilience indicators

Since indicators as a representative tool for analysis in complex systems is critiqued, we viewed indicators as "something to look for and promote within an organisation". This is the most appropriate way of dealing with indicators in an organisational context, since it is complex and multilayered social system.

6.1 Focus in development of indicators

The work with developing a first set of indicators, started from existing body of theory and empirics in Improver Project.

From Improver Project D1.1, the international survey, arguments and reflections around organisational aspects of resilience are presented. Below is a list of organisational aspects as they often are presented today:

"we should look at ways to estimate how flexible procedures are, how adaptive planning is, how learning is managed in the organisation which manages CI facility"

"organisational resilience relates to the organisations and institutions that manage the physical components of the systems. According to the authors this type of resilience encompasses measures of organisational capacity, planning, training, leadership, experience, and information management that improve disaster-related organisational performance and problem solving" (Tierney & Bruneau, 2007)

"Factors that affect resilience are robustness […], resourcefulness […], redundancy […], rapidity […], interconnectedness, cross-functional stakeholders, anticipative capacity, stakeholders' cooperation, capacity to recognise threats, evaluation of the model used to obtain and retain competence, capacity to prepare for future protection efforts, and ability to reduce likely risks"

In D1.1 Ouyang, Dueñas-Osorio and Min (2012) give examples on how to achieve resilient capacities. The aspects are presented in a bullet list, but if one really reflects around the organisational aspects in how these aspects are obtained, it becomes complex clear that the organisational measures rather reflects the interpretation of them, not the actual organisational needs. The bullet list contains aspects like:

- *"Adjust and improve the organisational and administrative structure to increase early-warning awareness"*
- *"Adjust and improve the organisational and administrative structure to accelerate the emergency decisions, such as sharing information among stakeholders, reinforcing staff training to accelerate the response time, ingraining the interdependency-related culture awareness, adjusting the market structures."*
- *"Increase the variety and robustness of communication channels"*

These lists of organisational aspects are not unusual, it is seen in most formalised organisations today, maybe within a safety culture program or the overall company culture or code of conduct. They maybe appear easy to grasp and manage, but is highly interpretable and not that instructive. This becomes clear when examining the scientific literature on the subject. We found that the values/focus/scientific ideological basis were highly important when managing an organisation towards adaptability and flexibility.

In our contribution we wanted to capture *how* an indicator should be revised, created and interpreted for being able to promote organisational resilience, flexibility and adaptability. We found that existing sets of indicators lacked this aspect and therefore leave the management of them to the organisation's

own interpretation. The scientific literature also told us that many infrastructure organisations today has a too linear and mechanistic way of interpreting interactions and flows (Larsson, Dekker, & Tingvall, 2010). This is not suitable for complex systems. A set of organisational indicators that is interpreted in a linear manner makes the organisation unsafe and less prone to show resilient performance.

In crisis management especially, there have been several attempts in developing support for emergency response teams. One reason for many of these failing, is a lack of understanding of real work problem-solving and involvement of end users in the process (Norros et al., 2009). For bridging the gap between reality and technology, often based on a mismatching component failure paradigm model, researchers have tried to address emergency response through systemic methods and approaches. In the development of indicators our ambition was to capture the systemic aspects, so that organisations could get help in *how* to work with resilient performance. When stating resilient performance as a complex function, it becomes increasingly important to use a systemic model that supports real work challenges, and the non-observable and non-linear aspects of a socio-technical resilience and emergency response (see for example Abrahamsson, Hassel, & Tehler, 2010; Chen, Chen, & Li, 2012; Norros et al., 2009; Salmon et al., 2014; Stanton & Bessell, 2014).

6.2 Demands on indicator list

The analysis of the scientific theory and body of empirics resulted in demands on the indicators.

The indicators should…

- include an "instruction" in how to be interpreted (and not interpreted) for promoting resilient performance
- invite to ongoing reflection and analysis.
- encourage a systemic interpretation. Indicators should not easily lend themselves to linear and mechanistic interpretations
- promote a shared view on real work challenges and identification of work-as-done
- help the user in moving between abstract and detailed functions in the organisation
- encourage work towards complex goals. Indicators should not easily lend itself to existing counterproductive driving forces to optimise towards measurability, monitoring, high standardisation, control and formal compliance (Power, 1999)
- be a starting point that must be further developed
- be continuously revised in alignment with organisational and contextual development
- be able to manage the whole overall organisational structure, including how decisions about technology and artefacts are made.
- manifest and recognise human capacity and significance in real work practice
- promote use-driven artefact design within the organisation
- encourage the reflection around goal-conflicts and trade-offs
- promote work with identifying good outcomes and successful adaptive performance, not only minimising risks and threats.
- promote a learning through re-designing the structures, artefacts and conditions
- create dialogue and cross-border forums and promote collaboration

6.3 Indicators

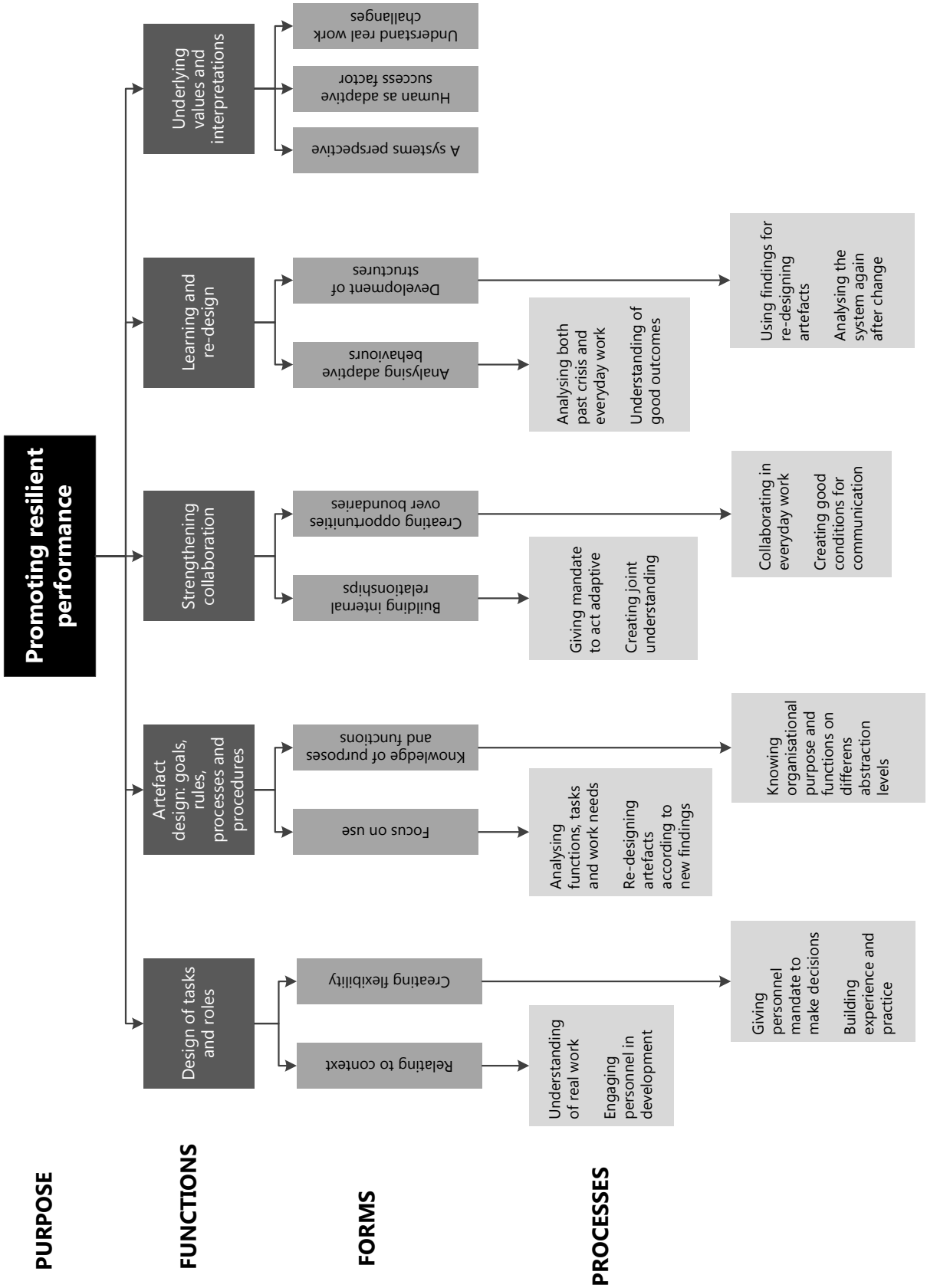

Figure 2. Structure of indicators on different abstraction levels.

The indicators on process level have a set of explanations; these are to be found in Appendix 2.

6.4 Further evaluation and design

The list of indicators must be evaluated further in real work, moderated and observed by researchers with systemic and usability competence. The organisation's feeling about how "easy they are to work with" is not enough. The work must be done in a design process by observations. The organisational "feeling" are today rooted in existing linear and sometimes overly bureaucratic compliance structures that permeates society (Power, 1999) and especially public organisations often induced by New Public Manegement reforms (Almklov & Antonsen, 2014). Organisational resilience is a new dimension and it is fully expected that organisations maybe struggle at the beginning. In a long-term perspective systemic resilient aspects need to be handled in a resilient manner throughout the entire legislation-user system.

7 Discussion

The purpose of the work described in this report was to aid practitioners in infrastructure to promote resilient abilities within their organisations.

The **primary objective** was to provide new knowledge about organisational resilience by studying real-world examples of how organisations in critical infrastructure tackle challenging situations.

The **secondary objective** was to show how such expressions of resilience can be examined and the outlook of doing so with existing methodologies.

7.1 Methodological issues

This study has largely been carried out using a literature review and interviews to shed light on the different cases. In reality, however, the same principles apply to these types of studies as to the organisational assessment of resilience, namely that a true grasp of resilient abilities can only be obtained if worked is observed directly, during an extended period of time. The optimal solution would have been to take part in the actual events that were studied instead of relying solely on the memories and conceptions of those involved. If this study of organisational resilience was to be continued, a core component of those studies would be field-studies during actual events.

A further limitation is that the authors have not been able to carry out the whole bulk of interviews themselves. The results obtained from an interview are always coloured by the ideas and attitudes of the interviewer. The theoretical background was distributed as a basis for the interviews along with an interview guide, but given that resilience is a concept open for interpretation, there is no guarantee that data from the respective living labs is entirely comparable. Continuing, the recruitment of informants was slightly challenging, not least because many of the organisations involved in the immigration event still operate under a heavy workload. This was especially true for the Swedish Migration Agency. In hindsight it has also dawned on the team that no actual immigrants have been interviewed, something that would have given an interesting complementary perspective on organisational operations.

7.2 Primary objective – New knowledge based on real-world operations

Despite the limitations mentioned in the previous chapter, the interviews conducted within this study have resulted in a number of observations relevant for this report's primary objective. Observations and analyses made under the primary objective also answer the IMPROVER main objectives 1. Understanding resilience and 2. Evaluation of resilience concepts.

Interviews conducted within this study were based on a number of resilience concepts derived from the literature, and the analysis has resulted in a taxonomy of organisational resilience indicators. Still, one of the main findings of this study has been that resilience does not primarily reside in simple organisational features, functions or resources, i.e. simple boxes to tick in an organisation's management system. Rather, some of the most important resilient behaviours in the observed cases had to do with adaptations - trade-offs and judgments made by professionals under the harsh conditions of real-world operations. In the same way, there are no easy organisational fixes to obtain the organisational features that underpin such advanced decision-making. Rather, for an organisation to support resilient behaviours it has to make serious investments, not least mentally, in human-centred practices for management, design, decision-making and collaboration. We see that applying such a human-centred and systems oriented approach could be the key to actually realising resilient abilities, because those abilities are created by people whose work must be supported in a variety of ways.

Observations from Case 1 in particular showed that the extent to which organisations were able to display resilient capabilities hinged largely on certain values, for example their way of relating to

established rules, regulations, procedures and processes. Again, these are organisational features that take serious efforts to implement and that may challenge many core assumptions within the organisation.

In large organisations such as governmental agencies where numerous functions work towards common goals, the issue of collaboration is particularly important, but the same conditions apply here – collaboration is not primarily supported by documents and high-level agreements, but on the actual interactions between organisational actors working to solve common problems. Again, striving for resilience is not only about knowing what organisational abilities to boost, but more about the way in which such abilities are sought. Even though indicators can readily be listed and integrated into existing indicator systems, the main question for any organisation is how these indicators are interpreted and approached in practice, i.e. what the organisation should do to strengthen resilience and how to go about it.

Focusing on the issue of resilience in critical infrastructure, it is important to point out that in most cases, governmental organisations struggled the most to allow resilient action. Since the decisions and activities of these agencies provide many of the basic operational conditions of infrastructure operators, it may be relevant to question what impact governmental agencies may have on overall infrastructure resilience.

7.3 Secondary objective – guidelines for the study of organisational resilience

Even though this study has not entirely followed the principles for the study of organisational resilience outlined in the analysis, several observations have been made around such methodologies, thus contributing to one of the IMPROVER main objectives - to develop a resilience management methodology.

In both theory and practice it has been demonstrated that resilience is created by the contribution of numerous organisational features, functions and activities, supporting the human capability to adapt in the face of surprising events. Because of this, the study of resilience must be systems oriented – it must acknowledge a broad range of factors contributing to resilient capabilities. In order to uncover all of these often subtle components, analyses must be carried out in close contact with organisational practitioners, enabling the formation of a rich description of work in context.

According to the experience of the authors, however, this ambition falls far from the reality of common organisational practices for indicator-driven management. Focusing on indicators is associated with several risks. First, the kind of bottom-up flow of indicator data often used in organisations is time-consuming and may hamper actual interaction between actors on different hierarchical levels, interactions that might in their own right have produced a deeper understanding of the organisational state. Second, since the administration of indicators is a time-consuming activity, actual interpretation of results may become a second priority to the aggregation of data. Third, when indicator follow-up is prioritised over other forms of organisational self-analysis, the kind of information that is most easily expressed as quantitative indicators may receive more attention than information that requires other forms of collection. Fourth, because it is common for resources to be stretched within organisations, and if the fulfilment of indicators is promoted by management, organisational functions may start to optimise towards established indicators, giving less attention to other parts of operations. Fifth, any interpretations of data still require a deep understanding of the organisation, again bringing focus to the build-up of rich experience (Power, 1999). Finally, a common theme in organisational research is New Public Management (NPM), a management trend with strong tendencies toward standardisation, proceduralisation and indicator follow-up (Almklov & Antonsen, 2014). These are tendencies that in large go against the driving factors behind organisational resilience, which again serves to demonstrate that the task of limiting organisational resilience to management through indicators may have negative consequences.

In many ways, the practices associated with the study of organisational resilience form a sharp contrast to common indicator follow-up. Because a proper study of resilience is systems oriented, probing the socio-technical context of work, it is conceivable that such a study in itself could function to strengthen organisational resilience. Systems oriented studies are carried out in close contact with practitioners, thus giving a chance for these practitioners to reflect on operations and contribute to the organisation's description of itself. Doing that may, in turn, allow them to see instances where the organisation is not adapted to the demands of the context, or how adaptations could be realised.

8 Conclusions

The purpose of the work described in this report was to aid practitioners in infrastructure to promote resilient abilities within their organisations.

The **primary objective** was to provide new knowledge about organisational resilience by studying real-world examples of how organisations in critical infrastructure tackle challenging situations.

The **secondary objective** was to show how such expressions of resilience can be examined and the outlook of doing so with existing methodologies.

8.1 Primary objective – New knowledge about organisational resilience

This report set out by looking at different definitions of resilience, and what consequences those definitions may have for the study of this subject. It was concluded that those definitions should be selected that serve to expose new ways of analysing organisations, giving new perspectives on system safety and efficiency. Based on this conclusion, resilience as flexible adaptation was taken as a simple basic definition for the use in the following studies.

The need for adaptive capacities in organisation stems from complexity, the fact that future events can never be fully predicted, and that human actors always have to fill a gap between pre-written procedures and the dynamics of real-world operations. These adaptations bring with them certain trade-offs, difficult decisions where different goals have to be weighed against each other and where compensations have to be designed in real time. These kinds of adaptations, professional judgments under severe conditions, were observed in all of the studied cases. Several of the cases also highlighted overall complexity in the operational context, a complicated web of actors, processes and events.

The extent to which organisations were able to display resilient capabilities hinged largely on certain values, for example their way of relating to established rules, regulations, procedures and processes, the way relations were formed between people and hierarchical layers within the organisation, or the perceived value of the human operator in the organisational whole. These values, in turn, determine how these organisations shape many of the basic conditions for resilient abilities to develop.

As an overarching theme it was concluded that striving for resilience is not only about knowing what organisational abilities to boost, but more about the way in which such abilities are sought. One such condition for resilience is the design and re-design of all organisational artefacts such as functions, processes, environments or tools. A second condition is the nature of internal and external collaboration, where the focus must be on actual human interaction and common problem-solving for good collaboration to evolve. A third is organisational learning that pays respect to the experiences of operational work, and that feeds into a structured process for re-designing the organisation.

In summary of the studies that were carried out, organisational resilience was described as the ability of an organisation to…

- Constantly re-assess itself and the situation using a diverse set of skills and knowledge
- Engage all parts of the organisation in idea generation and problem-solving
- Adapt and re-invent itself when faced with unexpected events
- Build the right support for sensemaking and action based on a profound understanding of practical working conditions
- Make decisions based on a firm understanding of real-world operations the current situation and the need for trade-offs
- Collaborate in a dynamic network of actors
- Stay humble in relation to the predictability of real-world operations

8.2 Secondary objective – The examination of organisational resilience

Both the literature review and the following case studies have given several hints to how organisational resilience should be studied. Since organisational resilience depends on a broad set of organisational features to develop, the study of this subject must be equally systems oriented. A systems oriented approach means paying close attention to the interactions within the system. This is coupled with a socio-technical approach, where the interplay between human, technological and organisational elements of an organisation are examined. In all such efforts, the understanding of humans and the necessary preconditions of human professional activities is key.

With regard to indicators, this report concludes that the socio-technical nature of organisational resilience might make it difficult to integrate in typical indicator follow-up activities. Just as the interpretation of technical indicators requires deep technical knowledge, the interpretation of organisational indicators requires deep understanding of organisational dynamics, humans and design. The study of organisational resilience requires a situated approach where work is studied from many perspectives, in context. The extent to which such studies can be transformed into indicators, where the results can be used in a meaningful way, could be questioned. Furthermore, the use of indicators is also associated with certain risks, some of which are mentioned in the discussion. In conclusion, while it is important to know what to look for, it is equally important how to look for it, and perhaps even more – how to affect those things that are studied. For an organisation to support resilient behaviours it has to make serious investments, not least mentally, in human-centred practices for management, design and collaboration.

9 References

Abrahamsson, M., Hassel, H., & Tehler, H. (2010). Towards a systems-oriented framework for analysing and evaluating emergency response. *Journal of Contingencies and Crisis Management*, *18*(1), 14–25.

Almklov, P. G., & Antonsen, S. (2014). Making work invisible: New public management and operational work in critical infrastructure sectors. *Public Administration*, *92*(2), 477–492.

Alvesson, M. (2011). *Intervjuer: genomförande, tolkning och reflexivitet*. Liber.

Andersson, J. (2014). *Representing Human-automation Challenges: A Model Based Approach for Human Factors Engineering in Industrial Practice*. Chalmers University of Technology.

Antonsen, S., Almklov, P., & Fenstad, J. (2008). Reducing the Gap Between Procedures and Practice: Lessons from a sucessful safety intervention. *Safety Science Monitor*, *12*(1), 1–16.

Antonsen, S., Skarholt, K., & Ringstad, A. J. (2012). The role of standardization in safety management – A case study of a major oil & gas company. *Safety Science*, *50*(10), 2001–2009.

Bergström, J., & Dekker, S. W. A. (2014). Bridging the Macro and the Micro by Considering the Meso : Reflections on the Fractal Nature of Resilience. *Ecology and Society*, *19*(4).

Bergström, J., van Winsen, R., & Henriqson, E. (2015). On the rationale of resilience in the domain of safety: A literature review. *Reliability Engineering and System Safety*, *141*, 131–141.

Bourbeau, P. (2013). Resiliencism: premises and promises in securitisation research. *Resilience: International Policies, Practices and Discourses*, *1*(1), 3–17.

Bowen, G. A. (2009). Document analysis as a qualitative research method. *Qualitative Research Journal*, *9*(2), 27–40.

Bruneau, M., & et al. (2003). A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities. *Earthquake Spectra*, *19*(4), 733–752.

Caldwell, B. S. (2015). Framing, Information Alignment, and Resilience in Distributed Human Coordination of Critical Infrastructure Event Response. *Procedia Manufacturing*, *3*, 5095–5101.

Chen, A., Chen, N., & Li, J. (2012). During-incident process assessment in emergency management: Concept and strategy. *Safety Science*, *50*(1), 90–102.

D1.1 International Survey, IMPROVER Report
http://improverproject.eu/2016/06/23/deliverable-1-1-international-survey/

D1.2 Lexicon of definitions, IMPROVER Report
http://improverproject.eu/2016/06/23/deliverable-1-2-first-draft-of-a-lexicon-of-definitions/

D2.2 Report of criteria for evaluating resilience, IMPROVER Report
http://improverproject.eu/2016/06/23/deliverable-2-2-report-of-criteria-for-evaluating-resilience/

Dekker, S. (2003). Failure to adapt or adaptations that fail: contrasting models on procedures and safety. *Applied Ergonomics*, *34*(3), 233–238.

Dekker, S. (2014). *The Field Guide to Understanding'human Error'*. Ashgate Publishing, Ltd.

Donahue, G. M., Usability, S., Weinschenk, S., & Nowicki, J. (1999). *Usability Is Good Business*. Farmington Hills.

Ejvegård, R. (1996). *Vetenskaplig metod*. Studentlitteratur.

Erik Hollnagel. (2009). *The ETTO principle: efficiency-thoroughness trade-off: why things that go right sometimes go wrong*. Ashgate Publishing, Ltd.

Gauthereau, V., & Hollnagel, E. (2005). Planning, Control, and Adaptation: *European Management Journal*, *23*(1), 118–131.

Grote, G. (2004). Uncertainty management at the core of system design. *Annual Reviews in Control*, *28*(2), 267–274.

Heldal, F., & Antonsen, S. (2014). Team Leadership in a High-Risk Organisation: The Role of Contextual Factors. *Small Group Research*, *45*(4), 376–399.

Hitchins, D. (1992). *Putting systems to work*. Chichester: Wiley.

Hoffman, R. R., & Woods, D. D. (2011). Beyond Simon's slice: Five fundamental trade-offs that bound the performance of macrocognitive work systems. *IEEE Intelligent Systems*, *26*(6), 67–71.

Hollnagel, E. (2012). Coping with complexity: past, present and future. *Cognition, Technology & Work*, *14*(3), 199–205.

Hollnagel, E. (2014). Human factors/ergonomics as a systems discipline? "The human use of human beings" revisited. *Applied Ergonomics*, *45*(1), 40–44.

Hollnagel, E., Nemeth, C., & Dekker, S. (2008). *Resilience engineering perspectives: remaining sensitive to the possibility of failure*. Ashgate Publishing, Ltd.

Hollnagel, E., & Woods, D. (2005). *Joint cognitive systems: Foundations of cognitive systems engineering*. CRC Press.

Hutchins, E. (1995). *Cognition in the Wild*. MIT Press.

Keller, W., & Modarres, M. (2005). A historical overview of probabilistic risk assessment development and its use in the nuclear power industry: A tribute to the late Professor Norman Carl Rasmussen. *Reliability Engineering and System Safety*, *89*(3), 271–285.

Kolar, K. (2011). Resilience: Revisiting the Concept and its Utility for Social Research. *Int J Ment Health Addiction*, *9*, 421–433.

Koskinen, K. U., Pihlanto, P., & Vanharanta, H. (2003). Tacit knowledge acquisition and sharing in a project work context. *International Journal of Project Management*, *21*(4), 281–290.

Larsson, P., Dekker, S. W. a, & Tingvall, C. (2010). The need for a systems theory approach to road safety. *Safety Science*, *48*(9), 1167–1174.

Leveson, N. (2004). A new accident model for engineering safer systems. *Safety Science*, *42*(4), 237–270.

Lissack, M. R. (1999). Complexity: the Science, its Vocabulary, and its Relation to Organisations. *Emergence*, *1*(1), 110–126.

Lundberg, J., & Johansson, B. J. E. (2015). Systemic resilience model. *Reliability Engineering and System Safety*, *141*, 22–32.

Lundberg, J., Rollenhagen, C., & Hollnagel, E. (2009). What-You-Look-For-Is-What-You-Find - The consequences of underlying accident models in eight accident investigation manuals. *Safety Science*, *47*(10), 1297–1311.

Milch, V., & Laumann, K. (2016). Interorganisational complexity and organisational accident risk: A literature review. *Safety Science*, *82*, 9–17.

Moorkamp, M., Kramer, E. H., Van Gulijk, C., & Ale, B. (2014). Safety management theory and the expeditionary organisation: A critical theoretical reflection. *Safety Science*, *69*, 71–81.

Muses, C. (2000). Simplifying complexity: The greatest present challenge to management and government. *Kybernetes*, *29*(5/6), 612–637.

Neisser, U. (1976). *Cognition and reality. Principles and implication of cognitive psychology*. QH Freeman.

Norris, F. H., Stevens, S. P., Pfefferbaum, B., Wyche, K. F., & Pfefferbaum, R. L. (2007). Community Resilience as a Metaphor , Theory , Set of Capacities , and Strategy for Disaster Readiness.

Norros, L. (2012). Analysis of work practices from the resilience engineering perspective, *3*(4), 1–8.

Norros, L., Hutton, R., Grommes, P., Colford, N., Liinasuo, M., & Savioja, P. (2009). Analysis of work demands of multi-agency emergency response activity for developing information support systems. In *European Conference on Cognitive Ergonomics: Designing beyond the Product - Understanding Activity and User Experience in Ubiquitous Environments* (p. 7:1--7:5). VTT Finland.

Ouyang, M., Dueñas-Osorio, L., & Min, X. (2012). A three-stage resilience analysis framework for urban infrastructure systems. *Structural Safety*, *36*, 23–31.

Patterson, M., & Deutsch, E. S. (2015). Safety-I, safety-II and resilience engineering. *Current Problems in Pediatric and Adolescent Health Care*, *45*(12), 382–389.

Perrow, C. (2011). *Normal accidents: Living with high risk technologies*. Princeton University Press.

Power, M. (1999). *The Audit Society: Rituals of Verification*. OUP Oxford.

Rasmussen, J. (1985). The role of hierarchical knowledge representation in decision making and system management. *{IEEE} Transactions on Systems, Man, and Cybernetics*, *SMC-15*(2), 234–243.

Righi, A. W., Saurin, T. A., & Wachs, P. (2015). A systematic literature review of resilience engineering: Research areas and a research agenda proposal. *Reliability Engineering & System Safety*, *141*(March), 142–152.

Salmon, P. M., Goode, N., Archer, F., Spencer, C., McArdle, D., & McClure, R. J. (2014). A systems approach to examining disaster response: Using Accimap to describe the factors influencing bushfire response. *Safety Science*, *70*, 114–122.

Saurin, T. A., Righi, A. W., & Henriqson, É. (2013). Characteristics of complex socio-technical systems and guidelines for their management: the role of resilience. In I. Herrera, J. M. Schraagen, J. van der Vorm, & D. D. Woods (Eds.), *5TH SYMPOSIUM ON RESILIENCE ENGINEERING MANAGING TRADE-OFFS* (pp. 11–16). Resilience Engineering Association.

Stanton, N. A., & Bessell, K. (2014). How a submarine returns to periscope depth: Analysing complex socio-technical systems using Cognitive Work Analysis. *Applied Ergonomics*, *45*(1), 110–125.

Tierney, K., & Bruneau, M. (2007). Conceptualizing and Measuring Resilience: A Key to Disaster Loss Reduction. *TR News*, (250).

Westrum, R. (2014). The study of information flow : A personal journey. *Safety Science*, *67*, 58–63.

Wilson, J. R. (2014). Fundamentals of systems ergonomics/human factors. *Applied Ergonomics*, *45*(1), 5–13.

Woods, D. D. (2015). Four concepts for resilience and the implications for the future of resilience engineering. *Reliability Engineering and System Safety*, *141*, 5–9.

Woods, D. D., Leveson, N., & Hollnagel, E. (2012). *Resilience Engineering: Concepts and Precepts*. Ashgate Publishing, Ltd.

10 Appendix 1 – Interview guide

Interview guide

Improver D4.3 Organisational resilience

General guidelines

- Non-normative approach - the aim is not to check for compliance
- Build on examples from reality
- Try to find general preconditions for successful work
- Focus on system interactions, interdependencies
- When statements are made, always ask for concrete examples

Resilient organisations:

- Continuously reinterpret the situation and are alert to early signals of surprise in their work and environment
- Jointly make sense of unexpected situations, taking the time to anticipate the impact of their decisions and monitoring how the situation develops over time
- Reach out for additional expertise irrespective of hierarchies and combine capability to the benefit of the situation
- Adapt by acting and collaborating in changing situations
- Understand what went well and what did not and the reasons for this, and learn from sharing adaptive practices
- Never assume a complete understanding and always prepare to adapt again

Introduction to the informant

- We are performing interviews within the EU research project Improver. The purpose of Improver is to investigate how critical infrastructure can adapt to and learn from serious events. What factors help or hinder this.
- We are searching for experiences from the Improver living labs that can help us.
- Discussions and interview questions are related to everyday work, but also to a specific event that the living lab has experienced.
- No names will be reproduced in any way. You as an informant are anonymous.
- No sensitive company information will be reproduced.
- The result of this work will be published in a work package report.
- We would like to record the interview in the case our notes aren't sufficient. We will not allow anyone else to listen to the recording.

About the informant

1. Which organisation are you from?
    a. Tell me a bit about this organisation – what it does / its responsibilities.

2. What is your occupation and your role within the organisation?
    a. Tell me a bit about what you do – tasks, responsibilities?
    b. How much experience do you have in that role?
    c. Do you have experience in other roles within the same industry/area?
    d. What is your work background?

During an event – case study

3. Can you tell me about *the event*? (An event the organisation experienced. In the Öresund region; the Refugees situation since autumn 2015. Describe in a timeline, perhaps supplied by interviewer).
    a. What parts of society did this event affect?

4. What was the role of your organisation during the event?
    a. What was your individual role?

5. What happened in your organisation when the event occurred?
    a. Did the organisation change in some way?
    b. Was your organisation forced to scale to the event, e.g. in terms of funding, manpower, tools or other resources?
    c. What was the workload like?
    d. How did your work change when the event occurred?

6. Who did you collaborate with during the event?
    a. Do you also have contact with these people during ordinary work? Does that affect your collaboration?
    b. How did your collaboration work out?
    c. Did you also have some contact with the general public? In what way?

7. How did you go about to get the right competence to handle this situation?

8. **If governmental/private:** How did you perceive the participation of voluntary/NGO actors? Give examples.
    a. What was their role?
    b. What do you see as their potential?
    c. Did these organisations complement the actions of your organisation? How?

   d. How do you imagine that the ideal collaboration between your organisation and voluntary forces would look like?
   e. What do you think differs between how your organisation and voluntary/NGO organisations can respond to events?
   f. Could you have done something more to tap into the potential of voluntary/NGO organisations?

9. **If voluntary:** How did you perceive the actions of governmental organisations? Give examples.
   a. How did your collaboration with other organisations work? Is there any room for improvement? (governmental/private/voluntary)
   b. Did you fill some kind of gap through your involvement?
   c. How do you think the public organisations perceive your organisation?
   d. What do you think differs between how voluntary/NGO organisations and governmental and public actors can respond to events?
   e. How do you imagine that the ideal collaboration between your organisation and public actors would look like?

10. How were decisions made in this situation?
   a. Did it work differently than during normal work?
   b. How does leadership work during a crisis? Are there any differences from normal circumstances?

11. How did you go about to gather information during this event? E.g. from other parts of the organisation, from the world outside, from media,
   a. Was it very different from how you do it in ordinary cases?
   b. What kind of information can be useful to you?
   c. What do you do with it?
   d. How do you share information?

12. Did you have to shift the distribution of resources during this event?
   a. If so, is that common when an event occurs?
   b. What kinds of resources can that be?)e.g. personnel, economical, material, competence, time)
   c. Can there be conflicts around resources? How are those handled?

13. During this event, how much of your work was controlled by instructions?
   a. Did you experience that routines could/couldn't guide your actions?
   b. Did you discuss this within your organisation during the event?
   c. Is this level of control normal for any event?

   d. Who makes decisions around instructions, both contents and use?
   e. What happens when there is a goal conflict, e.g. if you and your management have different views on your work goals or needs?

14. Tell me a bit about your physical working environment. What kind of equipment and support did you need to be able to handle this situation? (E.g. Support tools, computer systems, monitoring equipment, communication equipment, information handling, layout etc.)
    a. Do you use the same equipment both for ordinary work and for crises?
    b. Do they fit you needs? What can you do if they don't? What kind of influence do you have over this in normal circumstances?

15. On the whole, what are the differences between everyday work and work during events like these?

After an event

16. How has your organisation dealt with the experiences from this event?
    a. Do you think your individual experiences are heard? What about other parts of the organisation?
    b. How is this experience used now?
    c. How do you build competence within your organisation?

17. What was the main thing that your organisation learned from the event?
    a. What do you think are the main factors behind success in these situations?

18. Has this event affected the way your organisation works?

19. How do you look for new changes or risks that you need to act upon?
    a. Who is involved in this?
    b. When you detect something like this, what do you do?
    c. Then what happens in the organisation?
    d. Do you also look for opportunities? Give an example.

11 Appendix 2 – Indicators

Design of tasks and roles

Relating to context

Understanding of real work

A task becomes work in a context, work close to the practitioners

Rethink analysing isolated fragments, they always relate to each other

Strive for decision-makers having practical experience

Blunt-end managers with former experience in real work situations, loose this perspective over time

Root decisions in understanding of actual work conditions

Engaging personnel in development

Manifest the desire of engaging workers. Meet their needs.

Creating flexibility

Giving personnel mandate to make decisions

In retrospect, view decisions as locally rational

Challenge hindsight bias when analysing decisions in retrospect

Building experience and practice

Do not confuse role descriptions with actual skill, there are tacit aspects that couldn't be described in documents.

Recruit with diversity in mind, different perspectives enriches overall knowledge and perspective

Artefact design: goals, rules, processes and procedures

Focus on use

Analysing functions, tasks and work needs

Acknowledge cognitive needs in humans and the system

Challenge a strict focus on easily observable and measurable aspects.

Base development of artefacts on dialogue

Re-designing artefacts according to new findings

Have structures so that sharp-end worker needs are heard by decision-makers

View errors as a need for further development of the artefact, the artefact didn't meet real work needs and guide decision-making

Expect that constant questioning is needed.

Challenge organisational fears of failing, these could restrain adaptive abilities.

Knowledge of purposes and functions

Knowing organisational purpose and functions on different abstraction levels

Detailed processes are operationalisation of bigger purposes, functions and needs. In a stressed situation one must move upwards in abstraction. An everyday experience of this helps workers to be flexible

Knowing purposes and functions guides negotiations of procedures.

Perform the work in dialogue with sharp-end workers

Strengthening collaboration

Building internal relationships

Giving mandate to act adaptive

Listen to workers' fears about acting autonomously; reflect on how organisational aspects could be changes for manifesting the mandate better

Don't blame workers close to operations for making wrong decisions, instead strive for understanding why the decision was rational in their context.

Let sharp-end workers make decisions in stressed situations and later report upwards about their actions.

Creating a joint understanding

Between those who detect early signals and those who decide about actions.

Value personal relationships and friendships, collaboration grow over time in well-established interactions

Creating opportunities over boundaries

Collaboration in every day work

Reconsider clear responsible boundaries between departments or actors

Be aware that formal business agreements is not an assurance for real work collaboration

Focus on interactions, not pre-defined organisational departments and responsibilities

Be creative in identifying other actors to work together with, let everyone contribute.

Creating good conditions for communication

Strive for understanding other perspectives and local realities.

Analyse interfaces of interactions and flows in everyday work.

Be curious of the needs, fears and desires of the recipient, the recipient

Learning and re-design

Analysing adaptive behaviours

Analysing both past events/crisis and everyday work

Every day adaptive work reproduces in crisis

View success factors as embedded in real work practice

In event analyses, reflect around WYLFIWYF.

Understanding of good outcomes

Success factors lays in human adaptive behaviours, not pre-defined routines

Strive for understanding why actual work was locally rational, don't focus on counterfactual aspects, like "why didn't someone follow a routine"

Understand sharp-end workers. Lessons learned collected from higher hierarchical levels are not representative for sharp-end adaptive success factors

Development of structures

Using findings for re-designing artefacts

View errors as a symptom of poorly design pre-conditions and artefacts, don't view errors as humans violating procedures.

Reflect upon strictly administrative measures and what sharp-end workers face when routines co-exist collectively

Analysing the system again after change

New artefacts always change work.

Changes in one part of the system could unintendedly change something in another part of the system, both for good and bad

Evaluate changes so that changes didn't cause other success factors to disappeared

Underlying values and interpretations

A systems perspective

Change perspective to systemic foundations.

Challenge the idea that risks could be foreseen.

Be less scenario-dependent when foreseeing the future.

Acknowledge that surprises will occur.

Challenge the thought that interactions and flows are sequential and predictable. They constantly change and this requires flexibility.

Human as adaptive success factor

Value the social system as critical

The organisation has aspects that could not be aggregated from detailed procedures. The not easy observable aspects, like the social system, are important for overall performance.

Shifts the focus from blaming the individual for errors, to looking at the broader context of work.

Success factors in an organisation is tacit and experience based knowledge built over time and this is manifested in interactions amongst humans

Understand real work challenges

Recognise the gap between work-as-done and work-as-imagined.

Understand good outcomes

Don’t just focus on how negative outcomes can be minimised

Relate work to context

Acknowledge trade-offs

Challenge clinging too hard to established regulations, procedures and processes, discuss trade-offs between standardization and flexibility.

Be transparent with the trade-offs being made, engage in reflection around it

Challenge assumptions about real work.

Meet workers and observe real work challenges with the focus of understanding, not changing and controlling it.