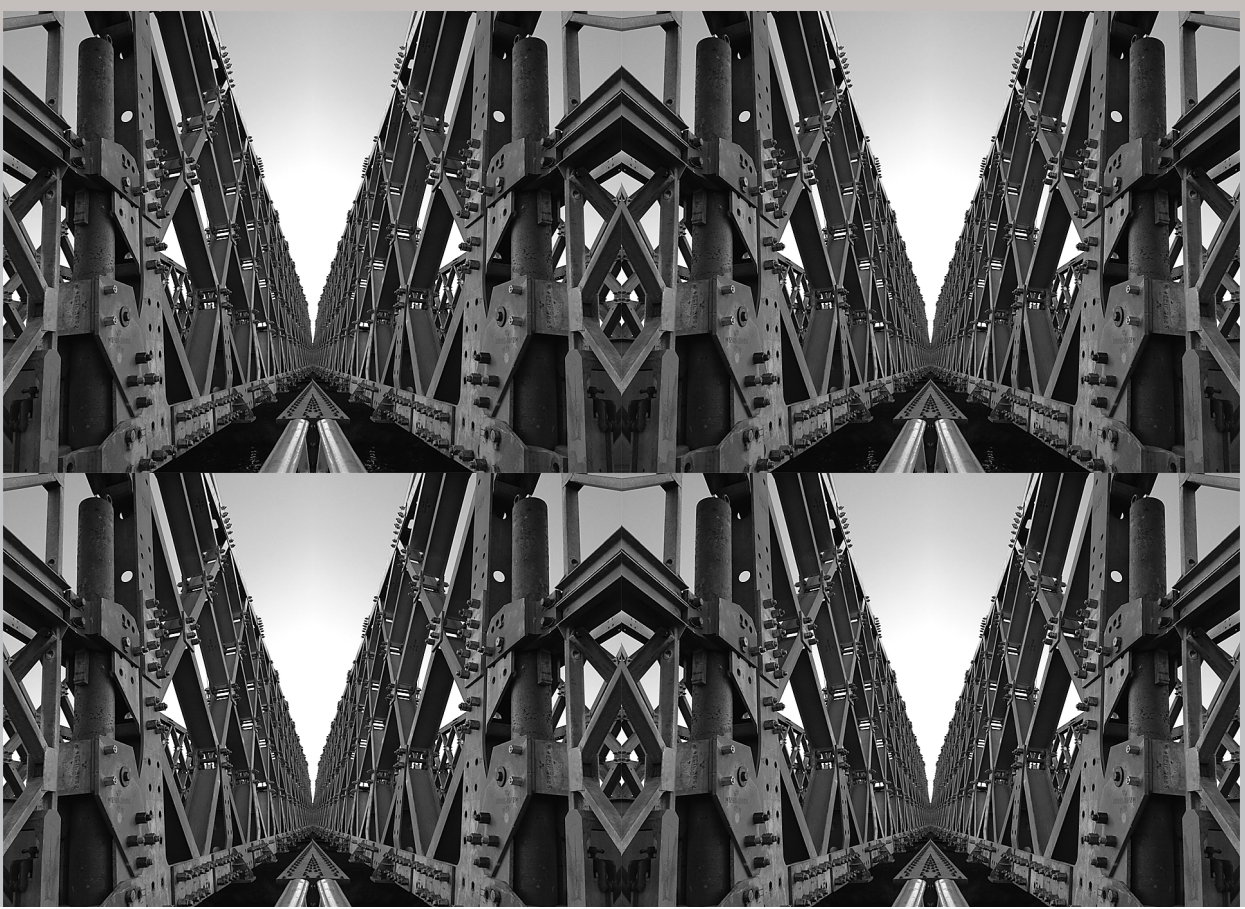
Organizational Lessons Learned

Natural Hazards Affecting Critical Infrastructure

MONIKA RYDSTEDT NYMAN



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Risk and Environmental Studies

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“Tell me and I forget, teach me and I may remember, involve me and I learn.” Benjamin Franklin.

Abstract

This thesis focuses on an issue often presented as a solution – albeit a debated one – namely learning, specifically lessons learned from natural hazard events. Empirically, this thesis examines flooding and avalanches in a Swedish context, centering on systematic feedback mechanisms and learning from extreme events. Opportunities to and constraints affecting learning and knowledge sharing are discussed. Through a literature review is the question if organizational memory can be built.

The thesis comprises four papers, collectively contributing a description of aspects of learning and feedback in a case study setting of the Swedish Transport Administration (STA) [Trafikverket], and providing an understanding of the present level of knowledge and awareness of climate change related natural hazards, and the risks associated with these phenomenon are perceived, as well as how knowledge sharing may give incentives and understanding for change. The notion of social learning is that individuals, groups, and organizations (and ultimately society) can learn from one another in a context, i.e. fostering mutual change. The goal of learning and using feedback is to create an opportunity to address changes in a thoughtful and explicit manner. At the same time, there is an implicit idea that learning occurs automatically somehow, which is problematized on the basis of the cases in the articles.

An interdisciplinary approach was adopted to obtain understanding of lessons learned related to natural hazards affecting critical infrastructure in Sweden. Interdiciplinarity refers to the use of theories from different research fields to achieve synergies in the search for explanations and useful understanding. The different objectives and aims of each paper have increased the understanding of mechanisms related to aspects of feedback, learning and knowledge sharing after natural hazard impacts. Each paper also provides examples of opportunities and constraints to feedback mechanisms and learning in a collective context.

Sammanfattning

Denna avhandling fokuserar på ett problem som ofta presenterats som en lösning, nämligen lärande. Mer specifikt fokuserar avhandlingen på lärande från naturolyckor och återkopplingsmekanismer inom och mellan organisationer.

Empiriskt undersöker denna avhandling översvämningar och laviner i ett svenskt sammanhang, samt genom en litteraturstudie diskuteras om organisatoriskt minne kan byggas. Fokus är på att öka förståelsen av hur lärdomar relaterade till naturolyckor påverkar kritisk infrastruktur i Sverige: hur dess risker förstås, och hur kunskapsåterföring av erfarenheter används i det som kallas ”lessons learned”, där möjligheter och utmaningar beskrivs.

Målet med att lära och använda erfarenhetsåterföring (feedback) är att skapa möjlighet att möta negativa förändringar som extrema väderhändelser på ett genomtänkt och explicit sätt. Samtidigt finns det en implicit tanke att inlärning sker med viss automatik, vilket problematiseras, baserat på fallen i artiklarna. Möjligheter och utmaningar för lärande och kunskapsöverföring i kontexten extrema väderhändelser i Sverige problematiseras. Fyra artiklar bidrar med en beskrivning av aspekter av lärande och återkoppling i Trafikverket, och hos dess entreprenörer. Avhandlingen ger en uppfattning om kunskapsnivå och förståelse för klimatrelaterade naturolyckor, samt hur återhämtningsförmåga (resiliens) kan byggas utifrån kunskapsöverföring och lärande.

List of included papers

This thesis is based on the following papers, which are referred to by their Roman numerals in the text.

I. **Rydstedt Nyman, M**., Johansson, M. & Liljegren, E. (2015). Merits of using a socio-technical system perspective and different industrial accident investigation methods on accidents following natural hazards: A case study on pluvial flooding of a Swedish railway tunnel 2013.
International Journal of Disaster Risk Reduction 13 (2015) 189-199. http://dx.doi.org/10.1016/j.ijdrr.2015.06.004.

II. **Rydstedt Nyman, M.,** Johansson, M. & Liljegren. E. (2017). Systematic knowledge sharing in a natural hazard damage context: How organizational borders limit lessons learned.
Risk, Hazards & Crisis in Public Policy. 2018, 8:4. 356-380. DOI:10.1002/rhc3.12119.
http://onlinelibrary.wiley.com/doi/10.1002/rhc3.12119/epdf.

III. **Rydstedt Nyman, M.** (2018). Collective Learning in Organizations: Opportunities and Constraints: Case Study of an Avalanche Blocking a Railway Line.
Risk, Hazards & Crisis in Public Policy.
DOI: 10.1002/rhc3.12159. (In Press)

IV. **Rydstedt Nyman, M.** (2018). Can Organizational Memory be built? (Manuscript).

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Authors Contributions

The papers included in this doctoral thesis are the result of collaborative efforts between authors. However, the substantial contributions to these papers of initiating, formulating research questions, collecting data, analyzing data, and writing the text, were made by the main author.

The main author initiated the changes made to the socio-technical analysis model (Paper I), and to the collective learning framework (Paper III). Together with Associate Professor Magnus Johansson changes were made to Rasmussen's explanation of strategies and scale of accidents to fit natural hazards, which led to the outlining of aspect of adaptive measure and no measures taken (Paper II). Dr. Eva Liljegren has contributed expertise on land transport specifics. Dr. Liljegren is one of the co-authors for two of the papers (Paper I & II). Associate Professor Magnus Johansson is co-author of two of the papers (Paper I & II). Further, co-authors and supervisors have enhanced the analysis in parts through useful comments and suggestions.

Preface and Acknowledgements

This journey has been a great adventure and a tremendous opportunity for me. Without all the people at Trafikverket (the Swedish Transport Administration), this would not have happened. I am most grateful and awed by the visionary thinking the administration had on issues of learning and knowledge sharing related to climate change and natural hazards. Because of its ambition to enhance learning and knowledge sharing related to natural hazards by hiring me to conduct PhD studies, I was very lucky to be able to participate in visionary thinking in the administration on these issues. Many are those who supported me, explained issues or answered my questions. I would like to give a special thanks to Dr. Eva Liljegren, Trafikverket, for all the support and supervision, and to Adjunct Professor Peter Söderholm, Luleå Tekniska Universitet (LTU) and Trafikverket, for great discussions on the public defense, which helped me to focus even harder on my task. Christian Dalin and Eva Tegelid, Trafikverket, thank you for great discussions. I also want to take the opportunity to thank my steering group for great discussions and inputs to my work: Johan Jansson, Trafikverket, Håkan Nordlander, Trafikverket, Dr. Åsa Sjöström, SMHI, and Dr. Gunnel Göransson, SGI.

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Thank you all for believing in me!

A new chapter starts; I look forward to what it will bring in terms of new challenges.

Cheers!

Contents

Terminology

Terminology varies between disciplines and sectors. Often the same concepts are used with different meanings. The concepts used in this thesis belong to the specific terminology related to natural hazards, climate change adaptation and resilience, and the field of organizational learning. The central concepts used in this thesis are listed and described for clarity in Table 1.

Table 1: List of concepts and descriptions, with references.

CONCEPT	DESCRIPTION	REFERENCES
Adaptation	Ability to cope with change (Labaka, Hernantes, & Sarriegi, 2016). Climate change adaptation focuses on working with aspects of managing the consequences of present and future climate conditions (EEA Signals, 2009). Adaptation covers activities and policies that seek to prepare society for a changing climate, to reduce impacts of climate change effects (Eisenack & Stecker, 2012).	(EEA Signals, 2009; Eisenack & Stecker, 2012; Labaka et al., 2016).
Climate Change	The thesis looks upon climate change that has hydrological, climatological or meteorological origins (Integrated Research On Disaster Risk IRDR, 2014; IPCC, 2012, 2014; Labaka et al., 2016).	(Integrated Research On Disaster Risk IRDR, 2014; IPCC, 2012, 2014; Labaka et al., 2016).
Collective Learning	Collective learning resembles social learning, and is based on individual and team abilities to transform experiences and knowledge into useful products for the collective, which may become part of the collective memory.	(Gerlak & Heikkila, 2011; Heikkila & Gerlak, 2013; Ohlsson & Granberg, 2016).
Control Strategy	Control strategy is two-fold: 1. the need for adaptation of system boundaries, and 2. how to increase the awareness level of limitations by making boundaries visible for control. Notable is the fast pace of change in technology compared to changes in systems.	(Rasmussen, 1997; Rasmussen & Svedung, 2007).
Critical Infrastructure (CI)	Critical infrastructure is an asset, system or part thereof [...] that is essential to the maintenance of vital societal functions, health, safety, security, economic or social well-being of people, and disruption or destruction would have a significant impact [...] as a result of failure, to maintain those functions.	(European Council, 2008).
Disaster	Disaster is used by Wisner et al. (2012) for "a situation involving a natural hazard which has consequences in terms of damage, livelihoods/economic disruption, and/or	(Wisner, Gaillard, & Kelman, 2012).

	casualties that are too great for the affected area and people to deal with properly on their own."	
Disaster Risk Reduction (DRR)	DRR is defined by UNISDR (2009) as "the concept and practice of reducing disaster risks through systematic efforts to analyze and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management to land and the environment, and improved preparedness for adverse events." (UNISDR United Nations International Strategy for Disaster Reduction, 2009).	(UNISDR United Nations International Strategy for Disaster Reduction, 2009).
Learning Loops	Single loop learning deals with correcting first order errors, within existing frameworks, means and goals, and is seen as quite instrumental Double loop learning challenge underlying assumptions, goals and values set for the organization, theories in use, and changes therefore outcome. Triple loop learning moves further away from previous frames, and challenge the whole systems underlying protocols, triple-loop learning (Argyris, 1977, 1999).	(Argyris, 1977, 1999).
Lessons Learned	Lesson learned occurs in a setting of trusted groups, which share information and knowledge, with the aim to achieve adequate changes (Le Coze, 2013). These changes are both in cognition and behavior (Ohlsson & Granberg, 2016).	(Le Coze, 2013; Ohlsson & Granberg, 2016).
Natural Hazards	Physical phenomena that have a potential to cause damage and losses for humans and natural systems (IPCC, 2014). Natural hazard refers to the natural processes or phenomena of potential danger. "A potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation. Hazards can include latent conditions that may represent future threats and can have different origins: natural (geological, hydro meteorological and biological) or induced by human processes (environmental degradation and technological hazards)." (UNISDR, 2005).	(IPCC, 2014; UNISDR, 2005).
Resilience	The ability of a system, community or society exposed to hazards to bounce forward (Manyena, O'Brien, O'Keefe, & Rose, 2011). Resilience is the dynamic response to hazards, and it is forward looking with inbuilt redundancy and multiple paths for dealing with responses (Manyena, 2013).	(Manyena, 2013; Manyena et al., 2011).

Risk	Risk can be seen as a combination of the components of hazard, exposure and vulnerability. A concept based on event consequences and uncertainties, with the understanding of risk as a broad type of concept that exists in a context (Becker & Tehler, 2013).	(Becker & Tehler, 2013).
Vulnerability	When entities are adversely affected by certa.in hazards in social, economic or environmental ways (IPCC, 2012). Vulnerability implies cross-sectorial and multiple threats to functionality of societal structures. Vulnerability is the measure of the 'ease' with which an organization is pushed into a new state – often undesired.	(IPCC, 2012).

1 Introduction

Natural hazards will continue to pose threats to human activities and our society, partly because of climate change and aspects of fast development, urbanization, population and economic growth connected with environmental degradation. Both natural and man-made issues, in other words, correlate to threats and risks.

In the last decades, an increase in negative impacts of natural hazards has been noted (IPCC, 2012, 2014), partly due to better reporting systems and documentation of natural hazards, partly due to assumed increase in human exposure and social vulnerability to natural hazards, even if scholars suggest that social vulnerability has changed because of increased possibilities to assess and become proactive (Mechler & Bouwer, 2015). In light of predictions of more extreme weather events as one plausible effect of climate change (Kjellström et al., 2018; Pilli-Sihvola, Harjanne, & Haavisto, 2017), the need to analytically incorporate lessons learned in plans and policies for climate change adaptation is all the more urgent. Learning from previous undesired climate change impacts is seen by some scholars as a precondition for actions to be taken. When referring to change, it is of significance to understand the difference between incremental, transitional change, and transformative change. The latter builds on fundamental changes involving systematic reform and creating alternatives for existing processes and operations for the future. It calls for some sort of paradigm shift in how existing processes and operations are performed (Blythe et al., 2018).Change related to single loop and double loops of learning are presented by e.g. Argyris (Blythe et al., 2018).

The goals targeting climate change adaptation have been slow to gather momentum compared to how climate change mitigation has turned out. This applies to many Swedish governmental agencies and administrations, the Swedish Transport Administration (STA) included. Part of this can be discussed in terms of the controversy of adaptation, and fear of redirecting attention away from mitigating activities. The first reports addressing problems and opportunities of climate change adaptation came from the Intergovernmental Panel on Climate Change (IPCC). The reports of IPCC have also made clear that mitigating and adaptive measures are complementary. Still, despite the slow start on adaptive efforts, the STA was part of the Swedish Government Official Reports 2007 (Statens Offentliga Utredningar, SOU) (SOU 2006:70), in which society's vulnerability was highlighted. The vulnerabilities of the critical infrastructure were stressed in the

report on climate change increases, which may result risk of sudden events that could have negative effects on societal systems and structures. In the case of Sweden, the climate is expected to become warmer and wetter, with more frequent and intense floods, landslides, and erosion, but also experiencing drought and heat waves (Kjellström et al., 2018; SOU 2006:70), which will affect structures and systems. The preoccupation with negative aspects of risk and risk management can be counterbalanced with the argument that adaptive measures are most likely cost-effective in terms of addressing both mitigating activities and seeing measures taken as part of the national sustainability goal.

This thesis relates to several issues discussed and decided by the United Nations in the *Sustainability Goals to Transform Our World* (UNISDR, 2015). The UN agenda puts emphasis on the aims to "end poverty, protect the planet and ensure prosperity for all", which the 17 goals are set to achieve. To this end, learning and knowledge sharing are important to enhancing resilience and adaptation measures against climate change, thus averting its threat to critical infrastructures and society. The argument is that learning and knowledge sharing is part of Goal 9: "Build resilient infrastructure, promote sustainable industrialization and foster innovation". The first target of Goal 9 is discussed in this thesis in terms of systematic knowledge building for achieving collective learning (Heikkila & Gerlak, 2013) and collective memory (Ohlsson, 2016). Goal 13 reads: "Take urgent action to combat climate change and its impacts". Goal 13 highlights the importance of working towards and especially facilitating sustainable and resilient infrastructures, and of building and constructing high qualitative infrastructures. This thesis deals with building understanding and a knowledge base for facilitating changes, which is related to the overarching goal mentioned above of enhancing possibilities for prosperity for all people. Goal 17 reads:

> Strengthen resilience and integrate climate change adaptation in strategies and planning as well as policies, includes the targets...
>
> ...to lower impacts and consequences of climate change effects and to strengthen early warning system (EWS).

These statements may be addressed through building knowledge in organizations, which is part of the aim of this thesis. As stated in the *Sendai Framework for Disaster Risk Reduction* (2015), investing to prevent future disaster risk losses is cost-effective. Moreover, to use

knowledge may mean that organizations and society can become resilient towards natural hazards in a more substantial way.

In international agreements and policies natural hazard and resilience efforts are emphasized. In the United Nations' agreement *Sendai Framework for Disaster Risk Reduction,* the necessity of sharing information and cooperating in efforts to reduce disaster risk and to enable risk governance to build a resilient society is stressed. In, "*Sendai Framework for Disaster Risk Reduction,*" (#14, p. 11), we can read:

> There is a need to address existing challenges and prepare for future ones by focusing on monitoring, assessing and understanding disaster risk and sharing such information and on how it is created; strengthening disaster risk governance and coordination across relevant institutions and sectors and the full and meaningful participation of relevant stakeholders at appropriate levels.

Recent studies show that despite a more interconnected society, the dependencies between and among different systems are not in focus in the research fields on natural hazards. Rather, each field promotes (crisis) management and preparedness for each (narrow) field (Kuipers & Welsh, 2017). For this reason, it is important to merge social, environmental and technical knowledge, to propose technical solutions, as well as to develop abilities in society to prepare, be proactive and become more resilient in a changing world (Di Baldassarre et al., 2018). In line with the emphasis on changing aspects of vulnerability knowledge and learning aspects are of interest.

Disaster Risk Management (DRM) focuses on how society and its stakeholders can become adaptive and resilient (Sonnsjö & Mobjörk, 2013). Risk management may provide room for improvement of established structures and for changes in governance of institutions. Natural hazards have exposed weaknesses that can lead to changes and reinforce structures in society if they are better understood. Risk management is often connected with knowledge sharing and lessons learned. Lessons learned is one DRM path for building a resilient society. Knowledge sharing and learning in a collective context (organizations) may be successful ways of addressing some of the problems posed by natural hazards.

Lessons learned may be understood as a linear process with identification, dissemination, best proactive approach and

implementation of such practices, this is often found in industrial investigation methods. PDCA cycles (Plan Do Control Act) are used for change management (O'Brien et al., 2013)in a sense that take reality and the complexity that is imposed in consideration. Reality is complex with both constraints and opportunities to learn and make adequate changes from the lessons drawn – some minor, some enabling renewal, and some in policy changes (Nohrstedt, Bynander, Parker, & t'Hart, 2018) implying that different levels and scale is targeted or the arena for learning and change.

The complexity and interdependencies created through a global, nonlinear and potentially irreversible environmental change calls for an axial perspective of learning and feedback mechanisms (O'Brien et al., 2013). Some scholars argue, that certain events may fuel change and constructive learning, while other events may be followed by conservative reactions, or by facts and evidence of events being ignored (Jansen, Claassen, van Poll, van Kamp, & Timmermans, 2018; Nohrstedt et al., 2018).

Risks associated with natural hazards are often described as a combination of hazard, exposure and vulnerability. Risk is a multidimensional concept, generally involving uncertainties as part of the concept and its features (Jansen et al., 2018). Some of the uncertainties depend on the multidimensional aspect of the concept, while others relate to aspects such as lack of scientific evidence or data, or even disagreement in science communities, and still others relate to hypothetical assumptions or inherent information tainting the understanding of risk (Jansen et al., 2018). How individuals, teams, organizations and society interpret risk and natural hazards is a critical aspect (Eiser et al., 2012). Although each hazard is context specific, some traits are similar to each of them – they often have ripple effects. (Nones & Pescaroli, 2016; Pescaroli & Kelman, 2017). These ripple effects are often of a cascading nature, threatening more than one system or structure. An adverse event may affect society and different systems both directly and indirectly. The event may affect the physical integrity of systems and their core functions, and operating conditions may change. Psychologically, individuals' abilities to act may be constrained, and the effects may damage social networks and the perseverance of individuals during and after the event, and at worst, there is no one to support or initiate measures.

Determining value depreciation post-event is difficult. Mapping the dependencies that have not yet been subject to damage, discontinuation, or stoppage is even more difficult. Some guidance can

be obtained through learning from what has occurred and been noted. The Swedish super storm "Gudrun", 2005, may serve as an example of the interconnectedness of infrastructures that had a devastating outcome.

> [On] 8 January 2005 super storm Gudrun slammed into the west coast of southern Sweden. Gudrun was the most devastating storm in modern Swedish history. Its hurricane force winds (33 m/s with gusts of 42 m/s) wreaked an extensive path of destruction across southern Sweden. Millions of trees were uprooted and broken and the combination of strong winds, falling trees and broken branches blocked roads, stopped rail traffic, and damaged electricity and telecommunications infrastructure, which caused phone service to stop working and 730,000 to lose power, some for up to 45 days. Sweden's crisis management system and the robustness of its critical infrastructure were exposed as inadequate. (Nohrstedt & Parker, 2014) (my underlining).

Vulnerability is shaped by socio-economic factors such as demography, land-use, prosperity in a community to name a few, but also by institutional ability to learn and make adequate changes. These factors, together with climate aspects that may cause meteorological, hydrological or geological change, constitute a society's vulnerability.

A resilient society, with the ability to manage disaster risk, calls for capacity and abilities in a system to withstand a major setback, such as disruptiveness from extreme weather, but, more importantly, to have abilities and capacities to move forward (bouncing forward) (Di Baldassarre et al., 2018; Manyena, 2013; Manyena et al., 2011). Aspects of understanding how to be proactive and protect structures in the sense of resilient and adaptive measures are important features for organizations and society to move or bounce forward (Di Baldassarre et al., 2018). Knowledge about the origin of a natural hazard, the development and aspects of consequences, together with information obtained from events, and different assets may make society less vulnerable, and give necessary information to build resilience. These aspects may become vital when trying to act proactively in maintaining critical infrastructures. Critical infrastructures (CI) are assets in society and part of a society's wealth and prosperity (European Council). CI are vulnerable to a changing climate and to natural hazards. These CI are often interconnected and rely on each other for functionality .(Birkmann et al., 2010; Brown, Seville, & Vargo, 2016; Doll, Klug, &

Enei, 2014; Huibregtse, Napoles, Hellebrandt, Paprotny, & de Wit, 2016; Laugé, Hernantes, & Sarriegi, 2015; Pescaroli & Kelman, 2017). This means that a single outcome does not exist; rather that events are complex with a multitude of interdependencies involving many different stakeholders at different levels of society with various degrees of preparedness, resources, abilities and vulnerabilities, and in knowledge.

Natural hazards are natural phenomena, which cannot always be controlled. Natural hazards can be triggered by activities made in society (human-made), as well as natural activities (for example, floods, landslides, drought, or heat waves). Society can build resilience in proactive measures, for example through flood or avalanche protection installments in an attempt to look ahead and make society and its structures resilient. Proactive measures may originate from learning and feedback mechanisms. The challenge lies in aspects of control related to natural hazards since natural hazards have their origins in uncertain conditions (Nones & Pescaroli, 2016; Pelling, 2010; Pescaroli & Alexander, 2016; Sonnsjö & Mobjörk, 2013). To optimize levels of resilience and the abilities to work proactively, combinations of strategies from different actors may give synergies, rather than independent action taken by actors as in prompt management and preparedness in each (narrow) field (Alfieri, Feyen, & Di Baldassarre, 2016; Di Baldassarre et al., 2018; Kreibich, Bubeck, Van Vliet, & De Moel, 2015; Kuipers & Welsh, 2017). This suggestion opts for combining knowledge and experiences from different fields into a crosscutting perspective of building resilience, and being flexible in events.

The processes of using previous experience and knowledge can become strengths in the future. The flooding in Central and Eastern Europe in the beginning of the twenty-first century are examples of natural hazards that have led to actions (Doll, Trinks, et al., 2014; Nones & Pescaroli, 2016; Pescaroli & Kelman, 2017).The EU *Flood Directive* (Commission, 2007) was implemented after these floodings in Europe. The flood directive emphasizes that European countries have to incorporate proactive measures in their ongoing efforts to become more resilient (Nones & Pescaroli, 2016; Pescaroli & Kelman, 2017). Further, the downsides of measures taken for protection should also be highlighted, such as protective plans that have led to levee effects of false safety from flooding (Di Baldassarre et al., 2017).

This thesis has a focus on learning in teams and in collective collaboration (organizations). Learning involves circular and relational

processes, in which the individual acquires new knowledge, and disseminates, translates and learns in a familiar context (Granberg, 2016; Heikkila & Gerlak, 2013; Le Coze, 2013). The processes of learning may result in a product as in lessons learned, which can lead to changes in cognition and behavior of the individuals, teams, and in the longer perspective the organizations (Heikkila & Gerlak, 2013). Some scholars argue that positive feedback from daily operations and success stories may have significance when individuals and teams contribute increasingly to learning and memory building. The reasoning behind is that positive feedback and attention create a positive atmosphere, which supports the importance of sharing information and experiences (Hollnagel, Woods, & Leveson, 2008; Rosness, Haavik, Steiro, & Tinmannsvik, 2016).

Other scholars suggest that teams learn (in organizations) when responsibilities and scope are clear, and understood (Granberg & Ohlsson, 2016; O'Brien et al., 2013; Stemn, Bofinger, Cliff, & Hassall, 2018). In addition, teams learn when members have a sense of security and trust, and have time and resources to disseminate, discuss and reinterpret issues drawn from experiences in their settings, and when members create shared mental models, and their ideas are aligned (Dekker, 2016; Lanier et al., 2018; Ohlsson & Granberg, 2016; Senge, 2006; Stemn et al., 2018). Still, shared mental models could lead to group thinking in which questioning and constructive criticism are lacking, which in turn may lead to weak incentives for learning (Ohlsson & Granberg, 2016). Shared mental models render some critique since they seem to favor consensus in organizations and teams, where rivalry and power issues are part of relations (Ohlsson & Granberg, 2016). The argument is that to move forward, there need to be some tension and rivalry for healthy relationships and appetite for change. Learning may be boosted when the management of organizations communicate incentives and mechanisms for handling rivalry and asymmetry in power (Ohlsson, 2016).

In an interconnected world where natural hazards pose a threat to critical infrastructures, it is important to examine and try to grasp how knowledge sharing and learning in a collective context may be part of building resilience in society. Argyris (1965) and Schön (1983) discuss the aspect of learning in relation to possibilities to reflect and adjust based on experiences. Related issues of building abilities are aspects of sharing across organizational borders. In a society with regulated tenders, aspects of precariousness regarding lessons learned are highlighted. Part of this uncertainty relates to aspects of governance within each organization, their means and goals, norms and values for

dealing with aspects of sharing knowledge and/or improving their own abilities (Brown et al., 2016; L. Field, 2017). These conditions may impede sharing across borders of organizations. Suggestions of building a well-defined structure for collaboration, with coordinated funding and encouraged collaboration, which calls for intentional processes for facilitating collaboration and coordination also at distances far apart geographically (or hierarchically)c.f. (Lanier et al., 2018), may enforce possibilities to successfully coordinate and collaborate also in cross border settings. Managers have great trouble to clearly show how information that is fed back is used to improve and make the organization efficient and resilient (Brown et al., 2016; Stemn et al., 2018).

The understanding presented in this thesis builds on case studies and a literature review, in which constraints and opportunities of organizational learning are outlined. Quite a few frameworks relating to feedback and learning exist, for example, on individual learning and collective learning (c.f.Argyris & Schön, 1995; Gerlak & Heikkila, 2011; Heikkila & Gerlak, 2013). This thesis and its case studies center on learning and knowledge sharing, which may lead to improvement regarding data aggregation based on incident reports and information of experience obtained through discussion and reflection among individuals and teams (c.f.Eiser et al., 2012; Granberg, 2016; Ohlsson, 2016; Stemn et al., 2018). Further, does the literature review present different meanings and understanding of how and if memory can be built in organizations. This thesis contributes to filling part of the gap relating to lessons learned and natural hazards.

2 Objective

The overall objective of this thesis is to contribute with further understanding of processes of feedback mechanisms and learning in an organizational setting. Learning and feedback are matters that have interested researchers for a long time, and are generally regarded as challenging (Argyris, 1999; Argyris & Schön, 1995; Heikkila & Gerlak, 2013; Lanier et al., 2018; Senge, 2006). The reason is that lessons learned provide opportunities to aggregate knowledge and to use previous experiences as lessons learned. Hazardous events can provide experiences through feedback mechanism into provided reporting systems that can result in lessons learned when aggregated and analyzed.

Possible challenges in an organization are cultural differences that are related to organizational structures, social networks and domains (Lanier et al., 2018). Feedback of experiences may led to changes in cognition and behavior, both of which are strongly linked to the culture and understandings of the individuals and how the organizations addresses such issues (de Moel et al., 2015; Heikkila & Gerlak, 2013). In a longer perspective, addressing these issues may result in a product of, for example, changed policies (Nohrstedt & Parker, 2014), and in storing knowledge as in building organizational memory.

The studies included in this thesis involve both short-term and long-term perspectives of learning and feedback mechanisms regarding disruption of and damage to critical infrastructures, such as roads and railways. The adverse effects of climate change and associated risks put learning and feedback loops into a new perspective, in which the connection to long-term adaptation and building of resilience is critical.

2.1 Overview of Objectives in Paper I-IV

This thesis consists of four papers, with different aims to enhance the understanding of learning and knowledge sharing based on natural hazards impacts on critical infrastructures (Table 2).

Table 2: Overview of aim, and study object, in each paper (I-IV).

Paper No	Aim of each study	Study objects
I	To test if industrial investigation methods can be useful in a different context, and enhance lessons learned from natural hazard impacts.	Case study of a well-defined pluvial flooding of a railway tunnel in Sweden, using industrial methods in a new context.
II	To increase knowledge about lesson learning in a Public–Private Partnership (PPP).	Case study of feedback loops in PPP setting between the STA and their contractor counterparts in Sweden.
III	To investigate if a collective learning framework can substantiate processes and products of learning from a natural hazard event in an organizational setting, and if learning loops can give an understanding of the type of learning taking place in an organization.	Case study of an extreme weather event blocking a railway line in northern Sweden.
IV	To examine if organizational memory can be built.	Review of articles from 1995 until today.

3 Research Methodology

This thesis rests on a social constructivist understanding of learning. A constructivist understanding holds that the learner is active and participates in constructing meaning in a collaborative setting (Kolb, 1984; Vygotskij & Cole, 1978), and that learning is not just assimilation and accommodation of new knowledge; rather, learning is constructed in a social setting, where the learning process is part of the context (Piaget, 1968; Vygotskij & Cole, 1978).

The key factor in the learning process is reflective interactions among individuals and teams in a collaborative process, in which cognition and behavior may change. It is accumulation of knowledge, which may have heuristic tendencies. Still, both knowledge and experience need to be relevant, make sense and be consistent, as well as to be incorporated in existing values, cultures, attitudes, and context to have an impact on changes in cognition and behavior.

The accumulation of knowledge is in this thesis focused on individuals in teams, and how organizations uses accumulated and scrutinized knowledge for cognitive and behavioral change, and (in the longer perspective) how knowledge is used to build a collective memory.

3.1 Qualitative Approach

The papers take a qualitative approach to single cases as the basis for insight, growing awareness, and understanding of aspects of knowledge sharing and learning. The thesis is based on inductive reasoning (Yin, 2013, 2014), with the aim to clarify and build knowledge about different aspects of lessons learned phenomena in terms of knowledge sharing and learning through feedback and feed forward loops related to impacts of natural hazards on land-transport systems in Sweden. Inductive reasoning has strengths and weaknesses. Since reasoning is based on knowledge existing at a particular time and space, conclusions may be drawn that later may seem incomplete or deficient in knowledge and facts (Yin, 2013, 2014).

3.2 Case study of the Swedish Transport Administration

To establish where learning and knowledge sharing may take place, the case study method was used. Each case provides a basis for understanding issues related to learning and knowledge sharing. The case study is an in-depth inquiry of a specific complex phenomenon in its real world context (Merriam, 2009; Yin, 2013, 2014). It can be a potent tool for communicating across borders to expose issues, raise awareness and give insight into situations.

In this thesis, the Swedish Transport Administration (STA) provides the setting, in which different events have provided information and data for an analysis of learning and feedback related to natural hazards. The scope is delimited to Sweden and event cases that have affected the Swedish Transport Administration and their land-transport systems. Further, a review of current understanding of knowledge and memory building provides grounds for future research – especially interesting are questions of how memory building and sharing of knowledge function in an interconnected world with compound issues to solve and aim for.

The event cases served as background material for the respondents to comment on in relation to their own experience and sense-making of feedback, feed forward, and lessons drawn that have changed cognition and behavior. The cases were used to give a fuller description of the reality as understood by participating respondents, and through documentation and archival information provided by the administration (STA). Through three in-depth cases the internal culture and understanding of learning and feedback is studies. Yin (2013) argues for the importance of context specifics and the context in case studies, and the findings in this thesis may give an indicative understanding of how other governmental institutions, but also how contracting organizations respond and behave in relation to learning and feedback.

Yin (2013) argues that cases need to be examined in a context to give a fuller understanding of different phenomena. The approach gives an in-depth, and usually limited, understanding of a case in the context that was meaningful at the time (Yin, 2014). By examining the information from the cases a broader and interesting discussion on the phenomenon of learning and feedback can be obtained.

Yin (2014) proposes six different sources for case studies:

A. *Documentations* may be reports and working documents that give a description of a matter;
B. *Archival records*, which strengthen a study through a backdrop of stable references in policies, methods, development over time;
C. *Interviews* in focus groups or single interviews give insight into perceptions, values and attitudes;
D. *Direct observations* of individuals and focus groups and the dynamics in a work setting;
E. *Participation observation* gives an immediate and contextual understanding of the case context;
F. *Physical artifacts* may show cultural meanings and operations that are important, for instance, through uniforms, logos or other artefacts, which may give a fuller description and insight into a case.

In papers (I-III), different case study approaches were used (Table 3). Archival material was mainly used for understanding previous decisions and investigations. In such cases documentation was in the forms of incident/accident reports and investigation reports that were more recent than the archival records. Furthermore, interviews with key respondents were part of the data gathering. Interviews were made both with Swedish Transport Administration employees and with contractors. The number of participants varies in the articles, from a handful to over twenty. The participating individuals were from different geographical areas, had different occupations from managers to project leaders, but they were all related to planning and maintenance of roads and railways. In one of the articles, direct observations were included in the material, in which observations of the team and individuals in the contextual setting contributed to the understanding of how feedback processes and learning were understood, and discussed among the participants. Artifacts and participant observations were not included in the approach since artifacts or paraphernalia were not expected to make contributions to aspects of knowledge sharing and learning, and the technique of participant observation is generally used in studies of a context itself, which was not the intention in this thesis. Paper IV is a review of articles, about organizational learning and memory (Table 3).

Table 3: Different sources used in the papers (based on Yin, 2014).

Paper	Archival records	Document	Direct observation	Participant observation	Interview	Artifacts	Peer review articles
Paper I	Yes	Yes	-	-	Yes	-	Yes
Paper II	Yes	Yes	Yes	-	Yes	-	Yes
Paper III	Yes	Yes	-	-	Yes	-	Yes
Paper IV	-	-	-	-	-	-	Yes

The interviews, data material, documents and direct observations were analyzed through Qualitative Content Analysis (Schreier, 2012). In the review paper, content analysis was used for key words, abstracts, and when suitable for the whole article. 52 articles were selected and after further scrutiny of key findings, 40 articles were included in the review.

A bias exists, since the author is employed by the STA. This is partly remedied by the fact that the author was externally recruited – with no prior connections to the STA – to conduct research on issues related to knowledge sharing and learning from natural hazards affecting the land transportation systems in Sweden on the same day as the PhD studies started. Part of the bias is avoided by the mere size of the organization. With over 6 500 employees it is difficult for the author to have major impact on answers or ideas concerning knowledge sharing and learning. Still, when interviews have been conducted and results communicated with employees of the STA, their ideas and comprehension may change.

It is important to consider reliability and validity. It is always hard to prove that individuals' opinions, perception and experiences are reliable/precise, and if the respondents would give the same answer twice to the same question. One dilemma to consider is the linkage to time and experience, but also to phrasing, mood and other aspects that can influence individuals and their answers in the data gathering phase of the studies. Qualitative studies do not involve yes and no answers, or quantitative numbers. A qualitative method is about individuals' subjective experience and thoughts. Another dilemma in case studies is that particular cases might be too specific and that the knowledge is only valid for the case. Case studies were in this thesis conducted at a local level, but may become global since the cases yield experiences and knowledge about aspect concerning problems, knowledge sharing and

lessons learned in an organizational setting as means to improve Disaster Risk Management (DRM) in terms of Disaster Risk Reduction (DRR), and Climate Change Adaptation (CCA). A further aspect to consider is the small number of cases. Still, if a case is seen as valid and important in its uniqueness, this case can give a better understanding of issues related to the objective of the study. Case studies can shed light on a gap in our understanding. To avoid too narrow a contribution, a contextual model for learning was applied to synthesize the material of each article.

The thesis draws on a contextual model for enhancing the understanding of opportunities and constraints identified in efforts to build understanding of and a knowledgebase related to natural hazards. The contextual model of learning is not a model as much as a framework to understand the complexity of learning in different contexts (Falk & Storksdieck, 2005). The contextual model originates from processes of learning in the context of museums (Falk & Storksdieck, 2005) In the setting of this thesis, the model has been developed to highlight opportunities and constraints for the processes of feedback and learning even stronger. The contextual model is arguably possible to apply to different sectors and settings for learning.

3.3 Organizational Contextual Setting: The Swedish Transport Administration

The Swedish Transport Administration (STA) is a governmental authority, responsible for the long-term planning of the national transport system for aviation, shipping, road and rail. Critical infrastructure systems of roads and railway play a significant role in Sweden's ability to prosper.

The networks consist of 100 000 km of roads and 15 000 km of railway lines. Road, railway, bridges, culverts, and system specific solutions are included in the systems. The network of roads includes both gravel roads, national roads and highways. The STA is responsible for constructing, operating and maintaining state-owned public roads and railways (SFS 2010:185). The maintenance of the land transportation is provided by contractors, which bid on tenders. The regulations (Regeringen, 2017; SFS 2010:185; SFS 2011:1131) establish that the STA is responsible for strengthening and preparing the critical land infrastructure against future perils. Moreover, the STA has mandate to facilitate reliable, available, maintainable, and safe infrastructure in

Sweden (SFS 2010:185). The STA uses different means to reach a reliable, available, maintainable and safe infrastructure network in Sweden and internationally (European Union, 2016; SFS 2010:185; SFS 2011:1131). Aspects of life-cycles, both long-term and short-term, are tools for planning, constructing and maintaining the networks of roads and railways efficiently (TDOK 2016:0281). Actions to be taken by the STA are based on both long-term perspectives for planning – a strategic plan for 20 years and an infrastructure task plan for a 15-year period – and short-term perspectives with an operational plan for a 3 year period, and a budget plan for one year.

The critical infrastructure of roads and railways is important to society's functionality and prosperity, and therefore essential to protect. Protecting and building a robust and resilient critical infrastructure rest on the notion of using previous experiences and lessons learned as means to enhance the control of the systems. The way to do this is through reporting systems (TDOK 2015:0184). The STA has multiple systems for reporting and aggregating data and information of different kinds, such as status of roads or railway lines, incidences, damage and accidents, and extreme events. The STA regularly meets with contractors to capture ongoing experiences that could lead to improvements. These systems and meetings are seen as important tools to provide the administration with updated information and data concerning, among other things, the status of land infrastructure and damage and disruptions caused by climate events (TDOK 2015:0184). These systems, divided into road and railway, provide data for improvements in future maintenance, and to track performances in tenders. Both road and railway accidents are examined for information to fix defects or deviations found in a safe manner.

The Swedish Transport Administration has since 2014 a strategy for climate change adaptation (CCA) (TDOK 2016:0882). STA's strategy focuses on both the system itself and on building a culture that encourages conditions for working proactively with commitment and possible innovation for CCA purposes. Part of the strategy is to have clear responsibilities, allocated resources, and using external and internal knowledge and experiences to enhance proactive CCA. By having a high level of preparedness and knowledge, the set goals are believed to be accessible. STA argues that it is important to work with both expected and unexpected scenarios to ensure a resilient land infrastructure, which is reliable, safe, and has environmental measures. The measures discussed and enhanced are of both structural and non-structural origins: steering documents, plans and policies that

take climate change into account, but also tangible resources, such as back-up equipment for swift deployment in case of a negative event, or different warnings systems, such as EWS (Early Warning Systems) and forecasting.

In 2016, STA decided on a climate change adaptation action plan in which eighteen different issues are listed as important to address to provide a safe, available, maintainable, and reliable land infrastructure (TDOK 2016:0882). Among these targets are data gathering, aggregated analysis, and a systematic use of provided information, which are all critical aspects of feedback and subsequent changes. These systems for data gathering and aggregating data are open to STA employees. Project leaders at the STA use these systems to track performances, faults, deviations and strengths in the systems, and of each constructor that has a tender with the STA. The Swedish legislation and EU directives specify that procurement has to be carried out for all services not provided by public actors (European Union, 2014, 2016; SFS 2016:1145; Trafikverket, 2010; UNISDR, 2015). The STA has since 1991 tendered contracts for all maintenance of state roads. Since 2011, contracts for maintenance of railways have become fully tendered. Legislation and regulations set the boundaries for how the STA is to work with procurement (Abdi, Lind, & Birgisson, 2013; European Union, 2014, 2016; SFS 2016:1145; Trafikverket, 2010, 2017). In the case of the STA, the number of tendering processes concerning operations and maintenance by external contractors has risen significantly since 1991. A few big construction companies tendered for these public contracts in 2016 (Konkurrensverket Upphandlingsmyndigheten, 2017). STA is the biggest tender organization in Sweden, with payouts of SEK 49 billion in 2016 (Abdi et al., 2013; Konkurrensverket Upphandlingsmyndigheten, 2017; Trafikverket, 2017). Most tenders are awarded to lowest price, which is not always the case in other countries (Abdi et al., 2013; Abdi, Lind, & Birgisson, 2014; Konkurrensverket Upphandlingsmyndigheten, 2017; Trafikverket, 2017). STA's largest procured contracts relate to construction, consultants, and services, and a large part concerns operation and maintenance of the state-owned roads (Konkurrensverket Upphandlingsmyndigheten, 2017). The tenders for maintenance of the railway are also concentrated to a few big companies with 96% of all contracts for maintenance, covering 85% of all railway in Sweden. Two thirds of the turnover are related to railway maintenance by two companies (TDOK 2016:0524). Both the road and railway networks have the same type of contracts. The contracts are divided into routine and structural maintenance. Routine maintenance involve tasks that maintain the functionality of the network at specific

standards the year round. This maintenance can be regarded as corrective maintenance. Structural (or preventive) maintenance is the work required for long-term asset management, and value improvement (Abdi et al., 2013).

4 Theoretical Approach

Each natural hazard is different and affects society and stakeholders differently, and it is therefore important to understand interdependencies (Di Baldassarre et al., 2018; Kuipers & Welsh, 2017). Natural hazards can be understood to make communities less resilient due to already existing vulnerabilities in structures and systems. These vulnerabilities are contextual, specific to each event and exposed structure or system. Still, vulnerability in society can imply cross-sectorial and multiple threats to functionality of systems and structures (Kuipers & Welsh, 2017; Mechler & Bouwer, 2015). Despite difficulties associated with aspects of pre-judging, society can take action and be prepared and act proactively. Disaster Risk Reduction (DRR) can be activated both in structural and non-structural ways in which technical solutions may reduce some exposure but also in different schemes of policies and plans for national governance and its institutions. Society may benefit if overlapping structural and non-structural measures in the efforts to make the whole system more adaptive, reliable and resilient.

Society's dependency on a reliable infrastructure has grown and the dependency continues to grow through interdependence among and between different societal sectors, as well as internally in organizations (Döös & Wilhelmson, 2016; Laugé et al., 2015; Le Coze, 2017; Mechler & Bouwer, 2015; Pauget & Wald, 2013; Pescaroli & Kelman, 2017; Rehak, Markuci, Hromada, & Barcova, 2016; Snelder & Calvert, 2016; Soltani-Sobh, Heaslip, Stevanovic, El Khoury, & Song, 2016). Natural hazard events affecting the grids of critical infrastructures can tilt the balance and draw attention to problems and dependencies among various stakeholders (Birkmann et al., 2010; Nohrstedt & Weible, 2010). Using this imbalance to take action requires preparedness and understanding of the perils, which implies a comprehension of root causes and their consequences. The imbalance can also be used for reinforcement of the implementation of plans and processes, and also possible empowerment to facilitate general changes (Rydstedt Nyman, Johansson, & Liljegren, 2017).

4.1 Risk and Related Concepts

Risk is a concept that is associated with something dangerous, hazardous, or sometimes unpredictable with unknown outcome. Climate change induced natural hazards are seen as a risk where humans and human-made structures (i.e. critical infrastructures), economic values, and the environment are affected. Risk management aims to develop favorable outcomes to prepare for negative effects, to mitigate negative effects, and to avoid total surprise of effects that cannot be mitigated (Sonnsjö & Mobjörk, 2013). Moreover, risk management also targets the response and recovery phases. Proactive risk management in a natural hazard context is understood to have greater possibility to enhance changes towards resilience than a reactive approach.

Climate change is for many decisions-makers uncertain in terms of where and how it will affect their organizations and production. Often, decisions are made for a context-specific area, leaving out aspects of interconnections, even if these aspects may turn up in an adverse event (’t Hart & Sundelius, 2013; Kuipers & Welsh, 2017).

Previous research points to the importance of feedback loops for building understanding and knowledge around failure of structures built, and necessary risk reducing measures (Eiser et al., 2012; Stemn et al., 2018). Some of these scholars favor positive feedback and success stories as a positive method for sharing and building knowledge bases (Hollnagel et al., 2008; Rosness et al., 2016). It is argued that specific plans need to be implemented. Another perspective on making plans for climate change adaptation is to consider the multi-layered governance of critical infrastructures (Schulz, Zia, & Koliba, 2017). Different actors have different needs, means and goals, which may explain why certain aspects of DRR and CCA are not shared or used. Sometimes such actions may be deliberate; sometimes actions are based on not having the information that other actors have. Transforming DRR and CCA into effective actions requires a mutual recognition of short and long-term interest among the actors involved (Eiser et al., 2012; Lanier et al., 2018; Stemn et al., 2018).

Resilience has multiple meanings and, if functional, addresses multiple areas as in resilience of what, to what, and for whom at different scales (Eiser et al., 2012; Olsson, Jerneck, Thoren, Persson, & O’Byrne, 2015; Walch, 2018b). Resilience has become the widely embraced overarching concept, since it is seen as a positive antidote to

vulnerability relating to external factors such as shock and stress (Eiser et al., 2012; Manyena et al., 2011; Olsson et al., 2015; Walch, 2018a, 2018b). Resilient thinking rests on the notion that a deliberate transformation is required in which merits for and against change have been assessed, but also that resilience is prominent in choices made (Folke et al., 2010; Manyena, 2013; Manyena et al., 2011; Olsson et al., 2015). Resilience, arguably, includes possibilities for changing and remaining persistent, which is a paradox, but if aspects of adaptation and sustainability are seen as important elements in the concept, the paradox may become understandable. It is about building capacities to resist, adapt and to cross boundaries – but having capacities left to develop within desired frames (Folke et al., 2010) Resilience includes many different factors, not only technical aspects of capacity building. Di Baldassarre et al. (2018) discusses possible outcomes of extreme events and measures taken by societal stakeholders. There is always the possibility of total collapse, or of moving back (bounce back) to previous states and possibly similar vulnerabilities, or to move forward (bounce forward) into a new trajectory (Di Baldassarre et al., 2018; Kennedy, Ashmore, Babister, & Kelman, 2008; Manyena et al., 2011). Knowledge sharing and learning can be means to bounce forward through transferring previous local experiences and knowledge to a global context of cognitive and behavioral changes.

Walch (2018) argues that the resilience concept often overlooks power differences. Aspects of power and prerogatives are not prominent in resilience thinking but something to consider since it may have significance to how resilience is created, to what and for whom. Despite all these obstructions, the concept is useful as a bridging concept, since it takes both technical and socio-economic changes and persistence into account, as well as how to handle the extremes. In this thesis the understanding of resilience, rests on the notion of opportunity to move forward (bounce forward) (Di Baldassarre et al., 2018; Manyena et al., 2011).

4.2 Feedback and Learning

Learning and feedback are seen as part of a process for implementing changes in an organization. This implies a governance approach to improvements. Most of these processes involve reporting accidents and mishaps within an organization as a way to achieve positive changes (Stemn et al., 2018). Scholars argue that learning is rather complex matter, involving many actors, and levels of society (Le Coze, 2013;

Leveson, 2011; Salmon et al., 2014; Spiekermann, Kienberger, Norton, Briones, & Weichselgartner, 2015).

Processes of feedback and learning are often described and discussed as linear processes, especially within the industrial sector, while scholars such as Gerlak and Heikkila (2011; 2013), Le Coze (2013), Döös and Wilhelmson (2016), to name a few, argue that feedback and learning processes are anything but linear. Rather, learning processes involve multiple steps, which are connected in individual and team abilities to acquire, disseminate and transform experiences into a product of learning in a context (Döös & Wilhelmson, 2016; L. Field, 2017; Heikkila & Gerlak, 2013). Other scholars point to reinforcement through positive feedback, for example, by good examples, or good outcomes in an operation as part of learning processes and knowledge sharing, rather than the negative attention that near-misses, incidences and failures may bring (Hollnagel et al., 2008; Rosness et al., 2016). The positive atmosphere may serve as a basis for strengthening features of trust and the sense of making a difference. Sharing and learning may function in an organization with openness and flexibility, and among actors in the organization where the individuals are trusted and can make sense of their experience of how their tasks contribute to the whole (Döös & Wilhelmson, 2016; L. Field, 2017; Hovden, Størseth, & Tinmannsvik, 2011; Le Coze, 2013; Maslen, 2015; Nesheim & Gressgård, 2014; Stemn et al., 2018). Some circular loops for building competence and understanding are required, and the opportunity to estimate cost and benefits of the actions taken for the individuals and teams (Döös & Wilhelmson, 2016; L. Field, 2017). In other words, the learning processes requires anything but a linear approach and understanding of these processes.

The multi-layer governance of society is in itself a challenge and can be a barrier to stakeholders' ability to act coherently in adapting to critical infrastructures. Brown and her colleagues (2017) found that there is a great difference in the understanding of abilities and resources at different levels of an organization. Brown et al. (2017) highlight that senior managers have a positive and firm understanding of the organizations' abilities and resources to be successful in resilience efforts in contrast to other organizational levels. Suggestions to explain this may be of the access of information and a holistic understanding of issues that are dealt with. The governance of an organization plays a significant part in how and where sharing knowledge and learning may take place. Leaders and leaderships play a significant role in making knowledge sharing and learning loops possible. The argument is that resources such as time and abilities to reflect and learn from efforts

may enhance the chances to prosper in terms of lesson learned (Brown et al., 2016; Döös & Wilhelmson, 2016; L. Field, 2017; Granberg, 2016; Granberg & Ohlsson, 2016; Hagelsteen & Burke, 2016; Lanier et al., 2018; McFadgen & Huitema, 2017; Ohlsson, 2016). Other potential barriers might be lack of resources, unclear responsibilities and uncertainties coupled with boundaries within the organization and towards actors in other organizations (Davies et al., 2015). One critical condition is how to use one's experience and knowledge to generate a more adaptive critical infrastructure and build a resilient society.

Brown et al. (2017), Maslen (2015), Hovden et al. (2011) and Leveson (2011; 2004) emphasize the importance of understanding the hierarchy in an organization. Closed hierarchies, and power struggles can hinder the transfer of experience and knowledge among and between actors (Braut & Njå, 2013; Brown et al., 2016; L. Field, 2017; Holcomb & Hitt, 2007; Maslen, 2015; Nesheim & Gressgård, 2014). In addition, strong hierarchies with top-down management and great division of task and performance can lead to fragmentation of work (Nesheim & Gressgård, 2014; Størseth & Tinmannsvik, 2012), which undermines a profound understanding and a holistic view of problems, and can therefore obstruct sharing as means of improvement (Frankish, Roberts, Coad, Spears, & Storey, 2012; Spiekermann et al., 2015). Also, multilayered governance can be a barrier, with conflicting objectives, means and goals (Schulz et al., 2017). At the same time multilayered governance may be an opportunity for future management since many different perspectives can be found in feedback mechanisms that drive change (Lanier et al., 2018; Schulz et al., 2017). Therefore, one can argue that it is vital to understand different power-related issues and crucial to have them in mind while using knowledge and experiences to build a resilient society. The different barriers are also related to power and the prerogatives of decisions and actions (Brown et al., 2016; L. Field, 2017). Some attention to possible constraints is required as these processes may be faced by asymmetrical power distribution in an organization, or by the control of higher hierarchical levels within a system (Brown et al., 2016; L. Field, 2017; Maslen, 2015). Challenges that stem from differences in the complexity of hierarchies, and organization of responsibilities, along with resources and power (Brown et al., 2016; L. Field, 2017; Maslen, 2015). Granberg and Ohlsson (2016) describe how the differences in terms of availability of/access to information have impact on the smaller group (team) and on the organization, which may lead to changed cognition in the form of developed understanding of information, changes in mental frames and references, and not least changed behavior.

The process of feedback and learning includes important features, especially the will to change (Brown et al., 2016). Furthermore, steps for feedback and learning involve flexibility in organizations and actors wanting and having possibilities to acquire, critically explore, and discuss aspects of a problem (Döös & Wilhelmson, 2016; L. Field, 2017; Stemn et al., 2018). The process of learning is found in a context and situations in which the individuals seek to improve their own understandings, possibly encouraged and supported by governance processes in the organization (McFadgen & Huitema, 2017). Studies show the importance of a formally implemented strategy for capacity building in which governance approaches facilitate the implementation and enforcement of improved knowledge sharing and lessons learned (Hagelsteen & Burke, 2016; McFadgen & Huitema, 2017). Enhancing lessons learned requires reflection, mediation, and adoption of new policies to handle different problems as part of an ongoing effort to improve different aspects of the organization (Albright & Crow, 2015; Granberg, 2016; Ohlsson, 2016; Ohlsson & Granberg, 2016). Further, aspects of a secure and safe work environment are important for discussions and sharing to take place (Ohlsson, 2016). These aspects involve commenting on deficiencies as well as admitting mistakes. Dekker (2016) argues for a "just culture" permitting open reporting and discussions concerning critical events and near misses, which, according to some scholars, is crucial to creating proper conditions for learning and development (Le Coze, 2013; Ohlsson, 2016). Processes of lessons learned depend on what Spiekermann et al. (2015), Le Coze (2013) and Leveson (2011) call mutual trust, and mutual benefits between individuals, and among groups at different levels of the organization. In this process, input can be provided to the collective, potentially leading to changes in cognition and behavior at a collective level (Heikkila & Gerlak, 2013; Le Coze, 2013). Leaders and leadership are of fundamental importance to creating incentives for sharing knowledge and for lessons to be learned (McFadgen & Huitema, 2017). Scholars argue that the managers may create an environment for sharing and for change through a common interest alignment (Döös & Wilhelmson, 2016; L. Field, 2017).

Heikkila and Gerlak (2013) state that learning in a collective process is not mimicking or copying. Learning in a collective setting is rather a deliberate and strategic path to enable changes (Heikkila & Gerlak, 2013) when transfer of knowledge, acquired by the individual, translated and disseminated by the collective, is either aimed to reinforce existing behavior or to change behavior (Heikkila & Gerlak, 2013; Le Coze, 2013). Collective learning is not the aggregation of individuals learning abilities; collective learning is rather:

> ...a collective process, which may include acquiring information through diverse actions (e.g. trial and error), assessing or translating information, and disseminating knowledge or opportunities across individuals in a collective, and collective products that emerge from the process, such as new shared ideas, strategies, rules, or policies. (Heikkila & Gerlak, 2013).

This collective process involves individuals that sense that they can express ideas and try out new solutions without punishment or obstruction from others – peers or managers (Dekker, 2016). This collective process may manifest itself in aspects of communication and feedback. The whole concept of collective learning rests on the notion that members of the organization learn, can and want to act together to achieve goals for the organization, which can be seen as a unitary perspective with shared interest and common mental models of these interests (L. Field, 2017; Granberg & Ohlsson, 2016). The mutual understanding that might prosper in a group or team may foster learning in terms of shared ideas and aspects of interaction that incite actions (Granberg, 2016; Ohlsson, 2016; Ohlsson & Granberg, 2016). These are based on the idea that individuals in an organization and the management have the same interest and strive for the same goal (L. Field, 2017). These interests might not be as mutual as previous organizational learning theories describe (Argyris, 1999; Argyris & Schön, 1995; Senge, 2006); rather, as scholars suggest, different interests shape learning and loops of feedback, in which deviation from the common unitary perspectives is identified, and described and understood as negative for the organization (L. Field, 2017). Deviation from rules and processes, are seen by some scholars as means for expanding risk. Still, deviation may also mean that new ideas are sprung from existing boundaries, and the concept of "Lean" is one such form of deliberate deviation in thought with clear incentives for "thinking out-side the box" and trying to come up with new ideas to improve and expand the operations, which could lead to better and more efficient ways of producing (Petersson, 2017).

Learning from experience is founded on the idea of thriving through changes based on previous experiences. The idea to improve and change rests on the notion of feedback given by individuals and groups within an organization to provide information and data that can be used as means for learning, in other words leading to change in cognition and behavior (Albright & Crow, 2015; Lavell et al., 2012). Information needs to be fed forward as in how feedback information is used to enhance changes in dealing with similar issues (Brown et al.,

2016; Eiser et al., 2012). The process of learning relies on reflection and communication in the group, where the individuals become the carriers of the mutual knowledge, the learning agent (Granberg, 2016; Ohlsson, 2016; Ohlsson & Granberg, 2016). Aspects of learning in a collective setting, such as an organizations', require mutual interest and understanding related to the individuals' context and understanding of issues (C. B. Field, Barros, Mach, & Mastrandrea, 2014; Granberg, 2016; Stemn et al., 2018). Sense-making play a role in how lessons learnt is understood and used (L. Field, 2017; Granberg & Ohlsson, 2016; Stemn et al., 2018).

To change is a desired action for ending dependencies, and finding new paths for the future. Incentives need to be expressed and facilitated by leaders, or by agents, of the organizations'. Willingness to change has significance in an organization regarding how and to what extent the organization may change and work proactively with different issues (Brown et al., 2016; L. Field, 2017). Incentives need to be established and understood, partly for not challenging existing order too much, partly for establishing understandings for ones possibilities to succeed by strengthening the knowledgebase by sharing and draw lessons (Lanier et al., 2018).

Learning can have a heuristic tendency, incorporating newly acquired experiences in an already existing knowledge base and mental frames leading to interpretation based on preexisting norms and values (Heikkila & Gerlak, 2013), or single loop enforcement of ideas and experiences where the means and goals are the same but some adjustments are made. Further, McFadgen and Huitema (2017) have questioned the loops of learning and the feedback mechanisms as knowledgebase to be established. They rather suggest that is the governance processes where leaders are the facilitators of change, which play a significant role in how feedback and learning take place, if taking place.

Birkland (2009) states that to a great extent learning is understood as parts of reports. Rollenhagen et al. (2017) and Birkland (2009), object however to the claim that reports are products of learning. Instead, Birkland (2009) states that the reports are routine products, which can be labeled fantasy documents, and are products showing that the organization management level is doing something. Rollenhagen et al. (2017) and Birkland (2009) claim that these reports focus on lessons observed rather than lessons learned in a profound sense of collective learning, since aspects of feedback and feed forward are lacking. Despite the objections, Rollenhagen et al. (2017) argue that

investigations and reports could function as the basis for establishing weaknesses as well as strengths, and establishing if lessons have been learnt, provided that the organization has a culture that manifests the importance of reporting, has a systematic way to communicate and applies the use of experience in their activities (operations and practice) (Stemn et al., 2018).

In a strict sense, learning and knowledge sharing are not the actual goals; rather, learning should be seen as an ongoing activity for improvements and changes of processes, plans and policies. To promote learning from others, and to enable changes, some sort of empowerment mechanisms and established forms of learning and sharing must explicitly be in place and understood by parties involved in the processes (Braut & Njå, 2013; Brown et al., 2016; Davies et al., 2015). Learning and knowledge sharing are not value-free or politically neutral, and it is therefore important to understand where and how obstacles present themselves (Davies et al., 2015; L. Field, 2017). (Davies et al., 2015; L. Field, 2017).

5. Theoretical Model - Contextual Learning Model

Learning is viewed as a continuous dialogue between the individual and the social environment. Learning originates from both from tacit knowledge and experience as well as from formal education or training. Learning is driven by social constructions in a collective setting where the context plays a significant part of the sense making (Vygotskij & Cole, 1978). The context for learning plays a significant role in how an individual and team in an organization may enhance the capacities for bouncing forward. Top managements need to understand and address issues related to incentives for knowledge sharing and learning if they want these aspects to be part of efforts towards resilience and abilities to bounce forward (Eiser et al., 2012; Granberg, 2016; Lanier et al., 2018; Ohlsson, 2016; Stemn et al., 2018).

Change may be understood as a normal and natural response to conditions in an organization for which change means adapting to changing conditions. In line with this, there is the notion that the organization (leaders) permits adjustment and approaches of adaptation to match changed conditions (Döös & Wilhelmson, 2016; L. Field, 2017; Senge, 2006; Stemn et al., 2018). Power and prerogatives in an organization are usually not considered when change and adjustments are discussed (Brown et al., 2016; Döös & Wilhelmson, 2016; Maslen, 2015). Still, these aspects play a significant part in how, what and who benefits from change initiatives for resilience to occur (Walch, 2018b).

Learning and feedback are often seen and understood as implicit loops of feedback providing vital information that leads to change (Rollenhagen, Alm, & Karlsson, 2017). The idea of change stems from the idea that both cognition and behavior can change to enhance capacities and abilities in a long-term as well as short-term perspective. A general understanding of how learning and knowledge sharing are facilitated emerges from how daily operations – from incidents and failure in an industrial setting are handled, to risk interpretation of preparedness and responses of natural hazards are incorporated in daily operations (Eiser et al., 2012; Stemn et al., 2018).

Learning is here seen as a conceptualized and contextually driven effort to make sense of experiences, and this presupposes that resources for disseminating and reflecting on experiences are given to individuals and teams in the organization. The constraints presented range from general understanding and reporting to aggregating and analysing the

data reported, to resources and sharing, and discussing differences and perspectives, governance incentives, leadership and steering, values, means and goals, to name a few (Eiser et al., 2012; L. Field, 2017; Kuipers & Welsh, 2017; McFadgen & Huitema, 2017; Rollenhagen et al., 2017; Stemn et al., 2018).

Constructing a contextual model does not relate to making predictions of current or future processes. Rather, it makes it possible to show how complex learning is as a phenomenon. Learning is situated in many different contexts with different prerequisites for learning, which influence the outcomes of learning processes and products of learning.

As Falk and Storksdieck (2005) put it:

> The Contextual Model of Learning is not a model in its truest sense; it does not purport to make predictions other than that learning is always a complex phenomenon situated within a series of contexts. More appropriately, the "model" can be thought of as a framework. The view of learning embodied in this framework is that learning can be conceptualized as a contextually driven effort to make meaning in order to survive and prosper within the world; an effort that is best viewed as a continuous, never-ending dialogue between the individual and his or her physical and sociocultural environment. The Contextual Model of Learning portrays this contextually driven dialogue as the process/product of the interactions between an individual's (hypothetical) personal, sociocultural, and physical contexts over time.

A contextual model of learning is presented based on the studies included in this thesis and literature (Brown et al., 2016; Döös & Wilhelmson, 2016; Eiser et al., 2012; L. Field, 2017; Gerlak & Heikkila, 2011; Granberg, 2016; Kolb, 1984; McFadgen & Huitema, 2017; Ohlsson, 2014; Stemn et al., 2018; Walch, 2018b). The contextual model (Figure 1) presents target areas of opportunities with strengths that provide examples to build on, and constraints that exist both in the form of explicit barriers, and implicitly through underlying barriers. These barriers and opportunities are often embedded in the hierarchies and in the means and goals of an organization, as well as in governance incentives and leadership, and not least in the underlying socialized values, attitude and culture, established in an organization.

The contextual model (Figure 1) is applied to cases in a Swedish governmental administration, the Swedish Transport Administration (STA), but may be applied to many organizations and settings to study how and where learning takes place, as well as to identify barriers and constraints to feedback. Here, this contextual model provides an opportunity to assess where opportunities and constraints present themselves in aspects of learning related to natural hazards.

The contextual model is divided into different starting points, with risk involving (natural) hazard, exposure and vulnerability on the far left hand side in the model. Such risks might be unidentified, or are already being treated on the basis of systematic control of risks (Rasmussen, 1997). The risk of exposure to vulnerability and natural hazard affects critical infrastructures through extreme events with ripple effects and damage on different scale. Depending on governance of the organization, with differences in approaching policy changes (L. Field, 2017; McFadgen & Huitema, 2017; Walch, 2018b), and in hierarchical levels, as well as means and goals, interest and power, values and attitudes (Brown et al., 2016) (listed at the bottom of Figure 1) incidences and damage may be reported into systems through different data and information (center of Figure 1). Reporting is a basic principle of managing risks (Rollenhagen et al., 2017). Differences in contextual aspects and the willingness to report, as well as the depth of reports will affect the aggregated analysis (L. Field, 2017; Stemn et al., 2018). The analysis may suggest recommendations to reinforce change, or the recommendations might be by-passed by existing biases or changed by existing heuristics (Brown et al., 2016; Nohrstedt & Weible, 2010; Walch, 2018b). The framework shows how data is then aggregated and analyzed to be fed into loops of learning. The loops of learning may be single, double or triple (Argyris, 1999), and may be seen as a product of learning as well as a process for learning to take place. Outside pressure and incentives from other societal actors is added to the model (Brown et al., 2016; Rasmussen, 1997), and how knowledge is shared, and/or incorporated in loops of learning.

The contextual model neither shows all the existing unintended or manifested barriers, nor how feedback and feedforward loops function in real life. The model could be described as more ad hoc, with simultaneous feedback and response, as well as lack of will or incentives for making feedback mechanisms work, or for reporting, or for analyzing aggregated information thoroughly. The model does not show how different governance approaches can influence learning. Neither does the model show possible power differences, nor the organizational maturity for implementing different changes, although

these still play a significant part for the outcomes (Brown et al., 2016; Walch, 2018b), and finally, the model does not take into account the pressure that other stakeholders might have on outcomes. In conclusion, this makes the model seem rather normative in its layout, despite the existence and influence that some opportunities and constraints mentioned in this thesis may have on outcomes. Despite these shortcoming, the contextual model is an attempt to show how complex organizational learning might be. The contextual model is used to highlight the rather complex processes for learning and feedback in organizations and between organizations provided by the case studies.

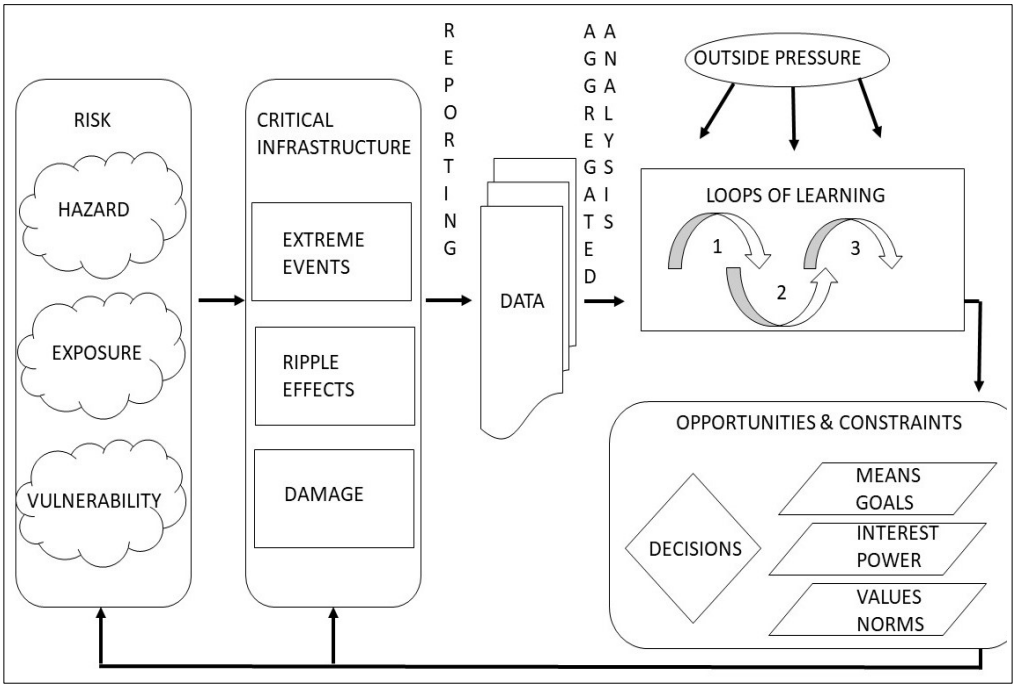

Figure 1: Contextual Model with opportunities and constraints for feedback mechanism and learning. On the left side in the figure risks, consisting of hazards, exposure and vulnerability, followed by effects on critical infrastructure, extreme events, ripple effects and damage. The extreme event and the damage feed into reporting of data that are aggregated and analyzed, and may become feedback loops of learning – 1) single loop, 2) double loop, 3) triple loop. All these aspects are influenced by means and goals, interest and power as well as values and norms (bottom right hand box in the figure), which affect decisions that are taken. Outside pressure (shown in the upper right hand corner) may influence all aspects of the contextual model.

6 Summary & Synthesis of Papers

6.1 Summary of Paper I

Merits of using a socio-technical system perspective and different industrial accident investigation methods to study accidents following natural hazards: A case study on pluvial flooding of a Swedish railway tunnel 2013.

In Paper I, three commonly used industrial accident investigation methods were applied to analyze a cloudburst event through a chain of-event. The industrial investigation methods are linear in approach and often oversimplified, leaving out important factors, as Leveson (2011) has pointed out. The argument for using industrial investigation methods is to show that these methods, with their shortcomings, can be applied and used in other areas than first intended. A further aspect considered is that these investigation methods are well known and often used for investigating failures or incidences in many organizations.

The industrial accident investigation methods can be used for analyzing natural hazard events although the oversimplification and the kinds of hazard investigated are more hybrid than empirical or evolutionary. Empirical events are frequently small events that can be aggregated to target the reinforcement of weak barriers, or to remove the root cause of failure, and natural hazards are not purely evolutionary. As in medium-sized infrequent events where the focus is on control through processes and improved safety, or removal of faulty devices, attempts to build safer processes can be made. Together, these aspects are interesting to develop further on a scale of natural hazards, which could vary significantly. Furthermore, by using a sociotechnical approach in detecting features of feedback and feedforward loops, processes vital to learning can be detected.

Findings in Paper I suggest that the use of industrial investigation methods can prove to enhance the transfer of different aspects, which is why in-depth investigation and analysis were carried out. If an understanding of nested loops, as found in Paper I, could become common knowledge (Figure 2), aspects of sharing may be a vital instrument, as scholars have argued.

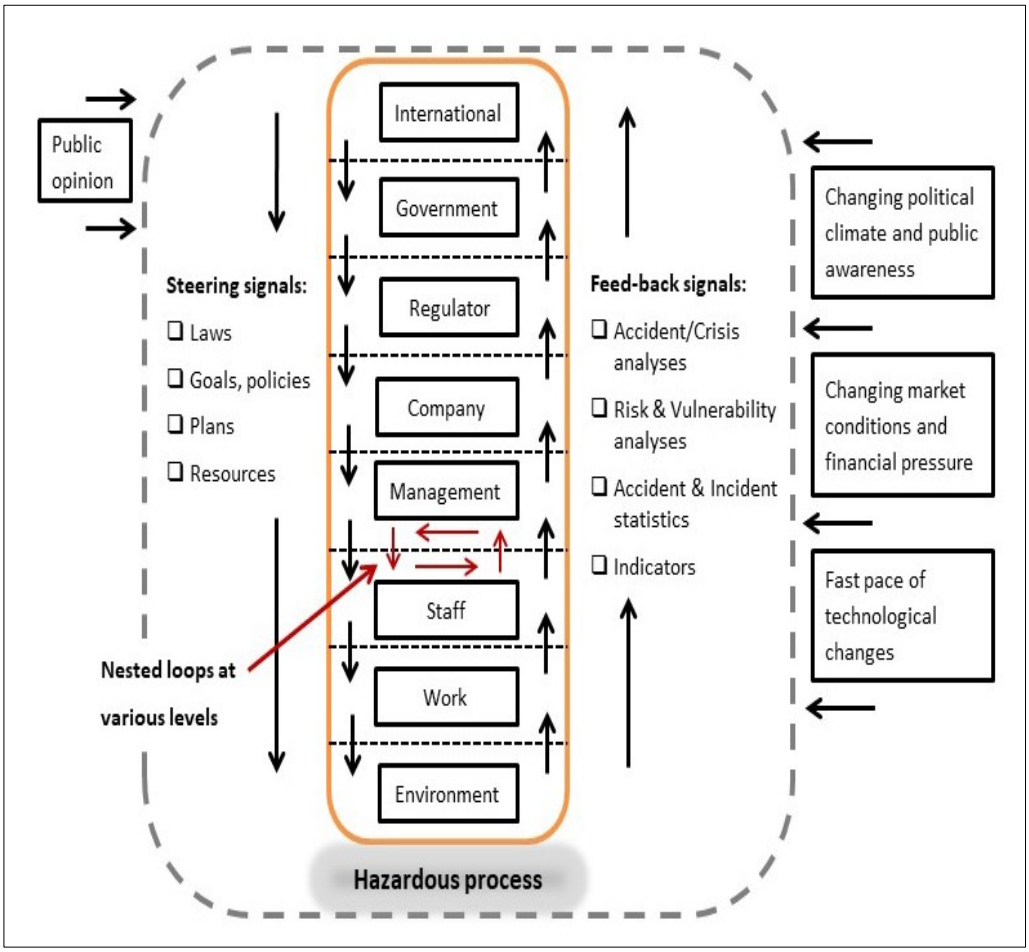

Figure 2: Adoption of Rasmussen's socio-technical model. Here the model is divided into 8 different tiers. Environment and international levels have been added to the original model. Each tier has its own responsibilities (apart from the level of environment), and can be seen as an actor dependent on the responsibilities and actions of other tiers. All levels are important and play a vital role in the system as such. Decisions, instructions and directions flow down from the top, while all kinds of feedback flow upwards and in-between actors at each tier. Outside input is also included. External input may change attributes and objectives. (Rydstedt Nyman, Johansson, & Liljegren, 2015) (Figure 4, in Paper I).

Findings in Paper I suggest that the three methods used have benefits for enhancing learning processes based on previous experiences. This applies especially to AcciMap, a method through which sub-levels, greater knowledge of communication patterns, decision processes and influences beyond the most obvious actors can be found, despite tendencies of having common stop rules for data gathering, or stopping on managers' initiative, or because of norms, values, or goals. In any industrial investigation, method or system, boundaries function as signals to stop the data collection and the analytical unwinding of threads. Boundaries can be based on many different considerations: abilities and willingness to proceed, power and power struggle, values,

norms and culture, and horizontal boundaries where a cause is detected in one surrounding rather than in the fuller context. These tendencies may hamper possibilities to use problems understood and knowledge in the desire to bounce forward in the aftermaths of an negative event.

6.2 Contextual Description of Results from Paper I

Merits of using a socio-technical system perspective and different industrial accident investigation methods on accidents following natural hazards. A case study on pluvial flooding of a Swedish railway tunnel 2013.

Industrial investigation methodology provides well-known and commonly used methods, which is an advantage for ensuring that an investigation will be approved and conducted. The investigation methodology allows for several approaches and opportunities for aggregating data and analyzing trends. The method selected for gathering data and information can give a knowledgebase to build on, even if a narrow methodological approach can become a constraint (Kuipers & Welsh, 2017). The data gathering will only get as deep and full as the investigator's mandate, which can give a shallow understanding of root causes. Above all, time is an issue, since most reports and investigations have little or scarce resources or time available for finding (root) causes. Some scholars also argue that reports in the aftermath of an event are mere fantasy documents, not providing depth or insight to underlying (root) causes, and is more observing what happened rather than take learning in consideration (Birkland, 2009).

The case studied here is a pluvial flooding event of a railway tunnel, where a passenger train was trapped for several hours. In the analysis of the event, three well established industrial investigation methods were used.

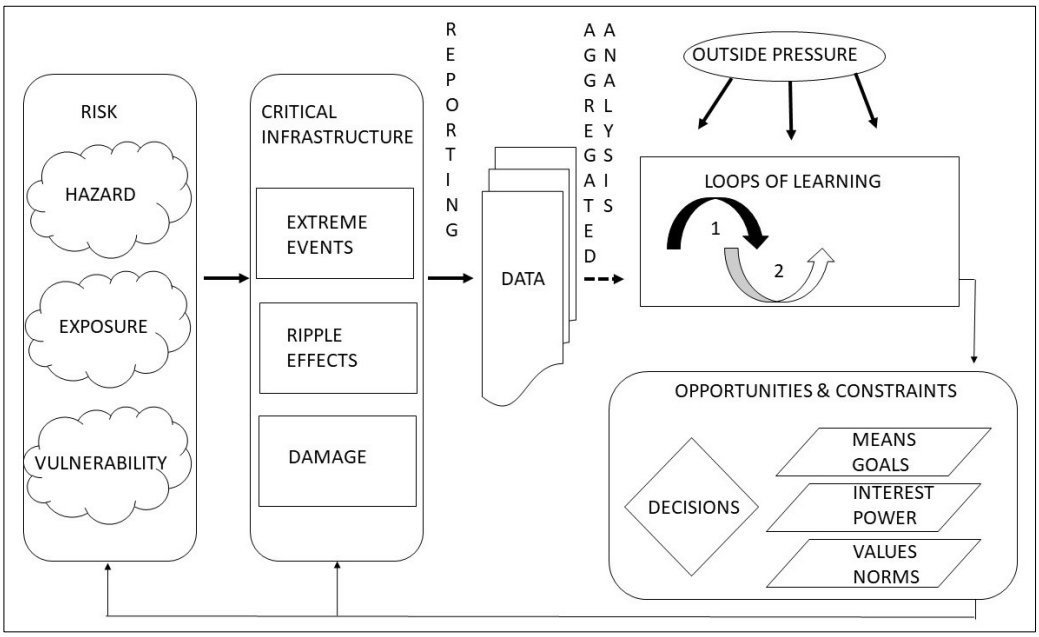

Figure 3: Industrial investigation methods include reporting (bold arrows), that may be analyzed at an aggregated level providing input to learning loops (dotted arrow). In this case the learning loops were of single loop origin (bold arrow), even if an understanding of double loops were traced. Feedback into the organization of aspects under Opportunities & Constraints were not identified by the respondents.

The contextual model further illustrated some findings in Paper I. Some evidence for data analysis and (some) aggregation of data shared were found (bold arrows, between reporting and data aggregation, Figure 3), even if the findings indicate scarce data and reporting (dotted arrow, Figure 3). The data shared may become loops of learning (bold loop 1, Figure 3), and to some extent be transferred to different levels and policies in a double loop of learning (loop 2, Figure 3). Loop 2 is less evident, and less strong for this case, much due to weak feedforward loops from the top levels in the organization on how and when reported experiences are to be implemented in the organization. Lack of communication from top levels in organizations is in general seen as a constraint that influence norms, values, culture and attitude in organizations (Brown et al., 2016; Döös & Wilhelmson, 2016; L. Field, 2017; Heikkila & Gerlak, 2013; Stemn et al., 2018). This weakness may in a longer perspective result in fewer reports and shared knowledge of experiences, which may lead to weaker knowledge base for future decisions.

Loops are expected to be established in the organization's memory, and then to follow the arrow through different decisions, and finally be fed back into the critical infrastructures (thin arrow at the bottom, Figure 3). In this case, no such findings were evident, making the feedback

seem rather local. The organizational memory may be influenced by constraints or opportunities (in the lower boxes, Figure 3). The organization's decisions may be influenced by outside pressure (upper right corner, Figure 3). These pressures may originate from public entities as regulators, or from private entities with interests that either coincide with the interest of the STA, or collide with STAs mandate and interest.

The findings in Paper I indicate that integration of organizational learning theory and industrial accident investigation methods is a promising, but still embryonic, way forward to improve lessons learning after natural hazards in the efforts to build more resilient societies. The approach to combine industrial investigation methods and organizational learning theory is embryonic since not much research has been done in the area. The combination may reveal the necessity for broadening the focus when conducting investigations. By integrating different perspectives of investigation methods used in the social and natural sciences, relations may be graphically represented as shown in Paper I.

In Paper I, AcciMap was applied in the analysis phase. This method gives a broader understanding of how feedback mechanisms work, and the method may be a useful tool to build incentives for knowledge sharing, which could become part of the organizational memory. Further, the ability to view events from different aspects, and identify relationships at micro, meso and macro levels may be prominent when coordinating integration of organizational learning theories with industrial accident investigation methods (Le Coze, 2013). A drawback related to AcciMap is that it is a method that requires time, abilities and capacities to conduct. In all investigation methodologies and analysis there may be stop rules that could hinder a thorough analysis of all aspect of root causes, which may lead to less profound aggregated analyses to base decisions on.

6.3 Summary of Paper II

Systematic knowledge sharing in a natural hazard damage context: How organizational borders limit lessons learned.

Paper II provides a greater understanding of the complexity of cross border sharing of assets such as knowledge, as it displays organizational inadequacies regarding lack of incentives to transfer local level experiences and knowledge to the top of the organization(s). In a Private-Public-Partnership (PPP) setting, obstacles to achieving goals as well as means to achieving them were identified. PPP have their challenges because of the fundamental difference in the means and goals governing public and private organizations. Signs of means and goal difference for each organization represented a constraint on sharing across organizational borders. These differences were found to manifest themselves in the kind of information and experiences that were shared between the organizations, and caused constraints to knowledge sharing and lessons learned. The complexity of differences in organizational goals are significant when it comes to knowledge transfer.

Findings in Paper II show that parallel feedback loops prevent interorganizational sharing, which in effect prevents effective learning for the STA. Learning and knowledge sharing across organizational borders are crucial to active risk management of adverse events. The imbalance of feedback concerning weather extremes and their effects impedes resilience and solutions of future problems.

It is necessary to emphasize dependencies to understand imbalances between different stakeholders in terms of resources, abilities and willingness to share experiences. Since dependencies and the asymmetric balance was not recognized or systematically worked with, the ongoing knowledge sharing became shallow between the local actors. Knowledge sharing was only found at a local level in a local context, which restricts possibilities for building in-depth and extensive knowledge bases for lessons learned.

6.4 Contextual Description of Results from Paper II

Systematic knowledge sharing in a natural hazard damage context: How organizational borders limit lessons learned.

In a dynamic society and a climate in change, it is, in a resilient perspective, important that transportation authorities make use of experiences and build knowledge from extreme weather events damaging the infrastructure. Learning is considered crucial to active risk management of adverse events by the STA management and stated in the regulations (Regeringen, 2018).

In line with the shift to neoliberal politics, it is essential to understand how knowledge transfer has developed and is practiced. The tendering process used in the case of STA stipulates that the stakeholders should enable knowledge transfer and the flow of information that is indispensable for the future handling of adverse weather extremes.

Looking at the results from Paper II using the contextual model as lenses, strong relationships within each different organization and weaker bonds and transfer of information across organizational borders can be seen, contrary to the belief that the tendering process builds advantageous relationships across organizational boundaries that will deepen over time. The findings indicate an imbalance in feedback of knowledge concerning weather extremes and their effects, which makes it difficult to increase resilience and solve future problems. The respondents from the STA were concerned about climate change, but did not provide evidence that they used information of climate change to enhance adaptive measures.

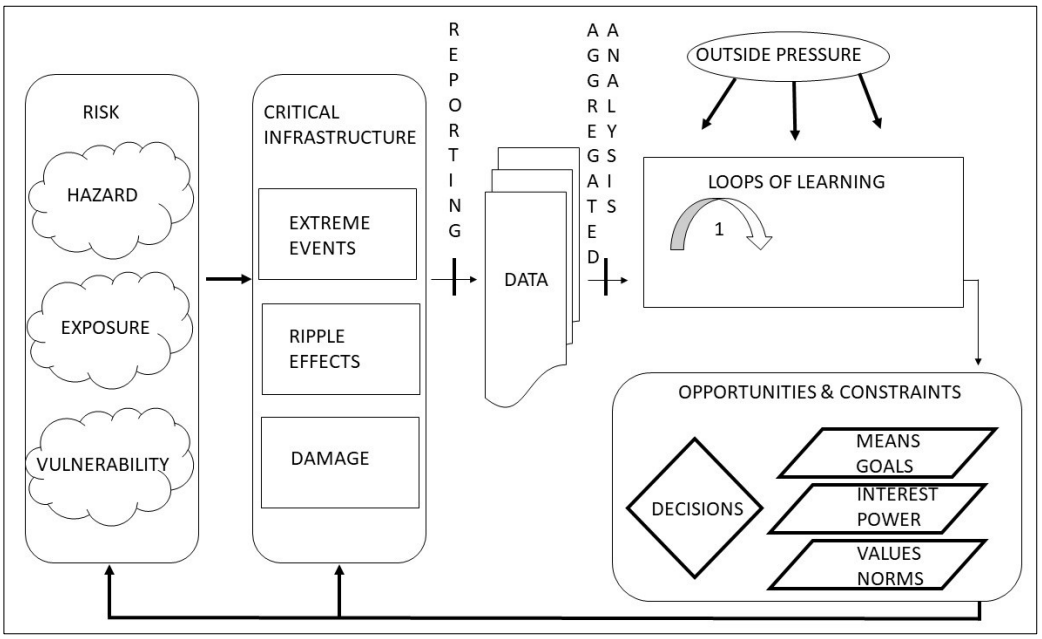

Figure 4: The contextual model in the analysis of Paper II shows lack of feedback (crossed arrows between reporting data and aggregated analysis). Where problems were discussed the actions led to single loop learning (1) of structural changes, incentives for feedback were weak (downwards thin arrow). The argument was that strong pressures from underlying organizational means and goals, interest and power, and values and norms (bold box borders and rhomb for decisions), may constrain successful feedback loops. Outside pressure may be as present as before, but is not considered to influence actions and decisions by the respondents.

A clear picture of parallel feedback loops emerged in Paper II, and these prevent inter-organizational sharing of knowledge – in effect prevent effective learning. The parallel systems make clear that the STA has a culture, norms, values and means and goals, while their tenderers have different means, goals, values, interest that influence feedback (bold box borders, bottom right-hand corner, Figure 4). If most knowledge remains unshared or in the organization, the knowledgebase will become weaker for the STA, especially in a longer perspective, when people leave for retirement or exit the organization for other reasons, which may lead to less resilient land infrastructure.

Lack of feedback, shown here with no arrows in Figure 4, is evident between reporting, data and data aggregation. Where feedback loops were found, these were single loops (loop no 1, Figure 4), leading to structural reinforcement or to re-building damaged infrastructure as it was before the event. This implies weak incentives for feedback and use of data and information, if provided. Further constraints could be partially explained by how tendered contracts are drafted, and how

tenders are monitored. Feedback of experiences and drawn lessons needs to be part of the contract and monitored like any other part of the contract; there is not room for volunteering feedback och sharing of experiences. These experiences may prove to be crucial for future handling of similar problems.

The tender respondents argued that the critical infrastructure is well-known and that their own expertise was enough to provide a safe, secure and reliable infrastructure, which are defensive routines to protect themselves and their professional role (L. Field, 2017), leading to weak understanding of the necessity to feed information back (thin arrow from loop box, Figure 4). The aspects of lack of feedback, or scarce feedback correspond with arguments that most transfer of knowledge takes place in a local domain and context (L. Field, 2017). Possibilities for shared values depend to a great extent on the degree of feeling of security and trust in the organization (Brown et al., 2016; L. Field, 2017).

Outside pressure does not seem to influence the understanding of how damage from natural hazard events is perceived by other stakeholders in society, which could be explained by different interests among and between different actors.

6.5 Summary of Paper III

Collective learning as opportunities and constraints: Case study of an avalanche on a railway line.

Using the collective learning framework (CLF) proved to be fruitful even if it did not fully explain the kind of learning product that was gained. It showed that knowledge sharing and gain of experiences needs to be part of contracts and followed up like any other aspect of the contracts. Most of the feedback information were of technical aspects – like the need of improved EWS and forecasting, and closer to machinery that could be used in similar events. The present processes of knowledge sharing and incorporation of learning products in the organizations involved were made visible through the application of loops of learning theories to the collective learning framework (CLF).

Paper III suggests that learning is a non-linear process only taking place in environments of trust, and where there are incentives for learning. Many scholars from different fields argue that trust, context and resources are features that promote abilities to learn and share among others and across organizational borders. This argument finds support in this case study. The opportunities for learning lie in people's abilities, incentives, and mandate to feedback information, which is also true in the case. In the contextual model (Figure 5) these preconditions are outlined as data gathering, translating information to make sense of the input, and dissemination of the information. The underlying structure, social dynamics and the technical domain strongly influence the outcome of sharing, which can lead to changes in cognition and in behavior.

The case study exposes dependencies in resources, and in different systems, such as Early Warning Systems (EWS), as well as in forecasting what could be described as the technical domain (Figure 5). Further, the case study shows that, despite previous experience of reporting and analyzing similar events and calls for reinforcements, the respondents expressed frustration that their experiences were not used to enforce changes. The findings suggest that the time elapsing between event and reinforced changes is significant. In addition, awareness of possible structural vulnerability to outer forces was apparent and the respondents understood the importance of being more adaptive and resilient, but they expressed frustration that their experience did not lead to formal change management processes. It is suggested that communication from the top management is crucial if members

(teams) of the organization are to understand where and how their feedback is used for enhancing the capacities and functionality of the critical infrastructure system. This could be discussed as part of the structure of the organization as well as the social dynamics (Figure 5). Inadequate communication is likely to affect feedback of experiences in terms of content and frequency, leading to fewer data and less aggregation of inputs from events. Figure 5 shows how underlying structures, social dynamics and technical domains strongly influence the outcome of sharing, which can lead to changes in cognition and in behavior, as mentioned above.

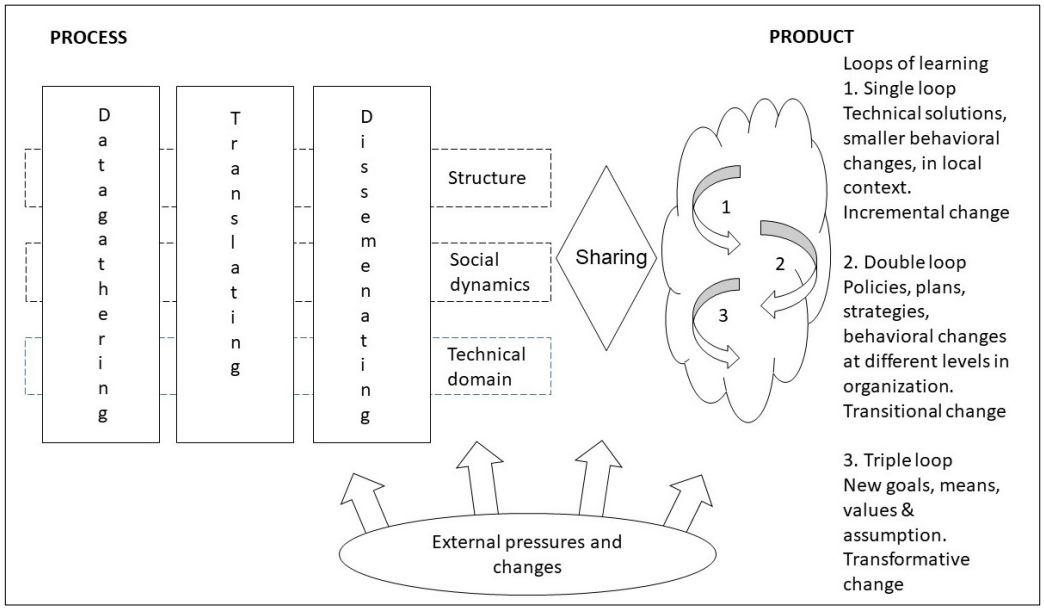

Figure 5: Contextual model with additions of outside pressure, and loops of learning, both in the processes and in the product of learning (developed from Argyris, 1999; Heikkila & Gerlak, 2013; Rasmussen, 1997; Rydstedt Nyman, 2018).

The findings suggest that teams learn and share in a context familiar to them. Learning is found at a local level, with single loop feedback as cognitive changes (no 1 in Figure 5). The learning taking place enhances structural changes of technical origins. In this case, for example, the EWS was reinforced. The double-loop learning (no 2 in Figure 5) taking place suggests changes in plans and policies, with time delays. These delays may be constraints in the structure of governance (top dotted lines in Figure 5), concurrent with lack of communication from the top level on how information and data are to be used successfully in making changes. Suggesting that underlying social and technical dynamics together with the organization structure have influences on outcomes.

6.6 Contextual Description of Results from Paper III

Collective learning as opportunities and constraints: Case study of an avalanche on a railway line.

The collective learning approach rests on the notion of feedback, reflection and discussion of experiences, and the assumption that tacit and formal knowledge is part of the collective memory, which is communicated by top-level managers. Incentives from leaders have been discussed by many scholars, and is seen as crucial for establishing a learning organization (Brown et al., 2016; Döös & Wilhelmson, 2016; L. Field, 2017; Heikkila & Gerlak, 2013). The communication by top managers is to prove the importance, and make knowledge sharing and memory building possible, in alignment with establishing a common ground to meet future changes.

Further, scholars argue that possibilities for shared values depend on the degree of individual's sense of trust and security in the organization, and among peers (Brown et al., 2016; L. Field, 2017). If individuals in the lower hierarchical spheres sense a lack of trust and ability to provide useful information, they may start to distrust leaders and the head of the organization. The issue of trust between team members is another important feature of how successful discussions and dissemination of information and experience are. The same issues underlie inter-organizational loops of feedback and sharing of information. Together, such issues may lead to the disappearance of ongoing dialogue and dissemination of problems and solutions, which is unfortunate since the dialogue and reflection that dissemination provides are seen as a crucial part of the construction of learning products (Heikkila & Gerlak, 2013).

Findings in Paper III show that underlying constraints of power, hierarchical differences and interest may obstruct the feedback and growth of organizational memory (Figure 6).

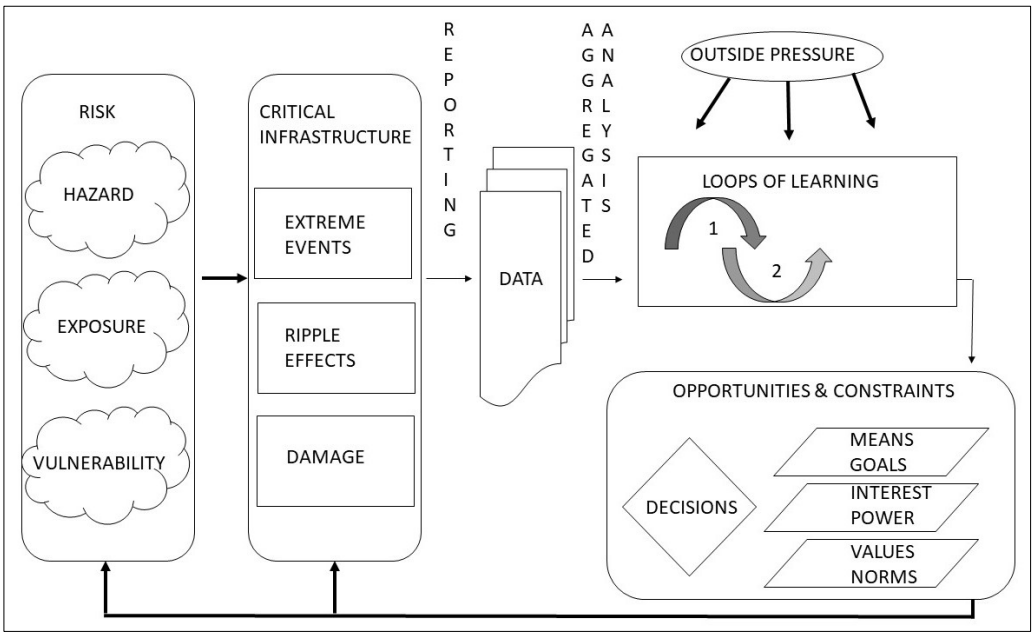

Figure 6: The contextual model shows weak arrows or incentives for providing loops of feedback. The bold arrows show that the underlying governance in this case becomes constraints for feedback and learning to prosper.

One crucial incentive identified in Paper III relates to scarce top down feedback within the organization. The indication of how and when experiences and feedback were used, is not communicated or manifested in any way in the organization, which could lead to less feedback in the future. Some of the respondents even argued that feedback may not be necessary since it was not used. This statement stands in contrast to the report (Trafikverket, 2017a) that is a direct response to feedback from previous events. One explanation might be the time lapse between feedback of information and data and documents that use the provided information in changed approaches, decisions and actions. Still, lack of communication may lead to fewer reports of damage from extreme events or feedback in general. Scholars argue that underlying tensions and conflicts of interests might be the greatest challenge to organizational learning and change; something that the respondents sensed, and indicated that it was a weakness in respect to dealing with extreme events (Brown et al., 2016; Döös & Wilhelmson, 2016; C. B. Field et al., 2014; Ohlsson, 2014, 2016; Walch, 2018b).

6.7 Summary of Paper IV

Can Organizational Memory be Built?

The literature review provide arguments that organizational memory is a key concept for many institutions, stressing the importance of deliberate change and progress in an organization. One common notion is that learning is an ongoing activity, and may lead to organizational efficiency and in the longer perspective to a resilient society.

Some scholars argue that a circular perspective as in PDCA cycles (Plan-Do-Check-Act) is a useful approach towards change; others suggest a more holistic approach in which integration of tacit and formal knowledge and incentives for systematic reporting, discussion and change are pursued. These two understandings are not standing in contrast to each other rather these complement each other. Many factors and prerequisites need to be aligned if organizational memory building is to work. Other scholars argue that culture and employment continuity are contributing factors to memory building, while still others argue that organizational memory cannot be built since experiences and knowledge are assets belonging to and kept by the individuals. Scholars also argue that in a context where team members trust, and rely on each other learning may occur (Ohlsson, 2016). When it comes to the trust and comfort of a team, the potential risk of groupthink without critical thinking needs to be considered. Groupthink may lead to irrational tendencies, and closing ranks for input from others (Janis, 1982). Groupthink tendencies may lead to less competitiveness, efficiency and deliberate change.

There is also a debate on whether or not an organization can learn, with some scholars arguing that an organization cannot learn; individuals are the learning agent with knowledge and understanding that in a longer perspective might derail organizations, if/when individuals with great experience and knowledge exit the organization.

The complexity of issues related to natural hazard events and the compound affects these have on society suggest the need for future research on interdependencies among different actors and on how efficient knowledge sharing and memory building can be promoted and available as an asset for all.

In Table 4, factors levels and characteristics or actions suggested by scholars on how and if organizational memory can be built are listed along with the opportunities and constraints are identified in the articles.

Table 4: Factors, characteristics or action, opportunities, constraints and examples of how memory building may be achieved.

Factors/ Levels	**Characteristics/ Actions**	**Opportunities**	**Constraints**	**Examples**
Organization	Accelerate efficiency and effectiveness Changes in rules and regulations Changes in processes Innovation and solutions for similar problems Combining codified and personal (individual) knowledge to the collective Use of narratives Deliberate culture building Deliberate memory building	Facilitate deliberate processes for knowledge growth Use narratives for develop knowledge sharing culture Positive reinforcements of operations	Differing Goals Character of Organization Power imbalances Biases (technological, behavioral, or economic) Novelty Time, speed and action - of and from events Poor Leadership and steering, Lack of Communication	Knowledge management (Hicks, Dattero, & Galup, 2006). Combining procedural and deliberate knowledge (Moorman & Miner, 1998) Implementation of lessons learned (Rydstedt Nyman, 2018). Positive reinforcements (Hollnagel et al., 2008; Rosness et al., 2016).
Collective/ team	Mutual understanding of problems Collaborative sharing	Combining tacit and explicit knowledge Informal process Organizational structures, to support professionals Positive feedback	Hierarchies Organizational structure Power imbalances Exclusion	Organizational factors supporting learning (Maslen, 2015). Coherent learning framework integrating micro and macro level learning (Lam, 2000). Collective learning framework (Heikkila & Gerlak, 2013). Professionals collaborative sharing (Granberg, 2016). Positive feedback (Hollnagel et al., 2008; Rosness et al., 2016).
Tacit/ individual	Routines Standardization Replication	Professionalism On-going activity	Focus on utilization. Individual asset Professional information sharing	Learning is an ongoing activity (Eiser et al., 2012). Positive reinforcement (Hollnagel et al., 2008; Rosness et al., 2016).

6.8 Contextual Description of Results from Paper IV

The foremost findings in the review is the ongoing struggle to demark memory building. A combination of differences in the understanding of the context and how learning and feedback may be used for building memory in organizations is important to understand. The learning organization seem to be a goal in itself, while one can argue that learning is a never ending approach. Organizations that strive to be competitive, and efficient could also say that they are a learning organizations provided that tacit and formal knowledge is used to emphasize change.

Some scholars suggest that employment continuity, culture and management may promote memory building, if there are processes allowing for discussions, questioning assumptions that has or are in use. This strain of research point to the importance of leaders and managers to provide for systematic discussions, disseminating problems to come up with common understandings of problems and future solutions. Some scholars argue that routines, rules, procedures, and culture (and shared mental models) is organizational memory.

By applying the contextual model (Figure 7) on the result can one see that the literature suggest all steps as important (darker arrows between all parts of the figure). The constraints that are presented by various scholars is foremost means, goals, interest, power, and in the cultural aspects (lower right hand box). These constraints can be difficult to detect since these are part of expectations both internally - the governance of the organizations and externally from other actors in society.

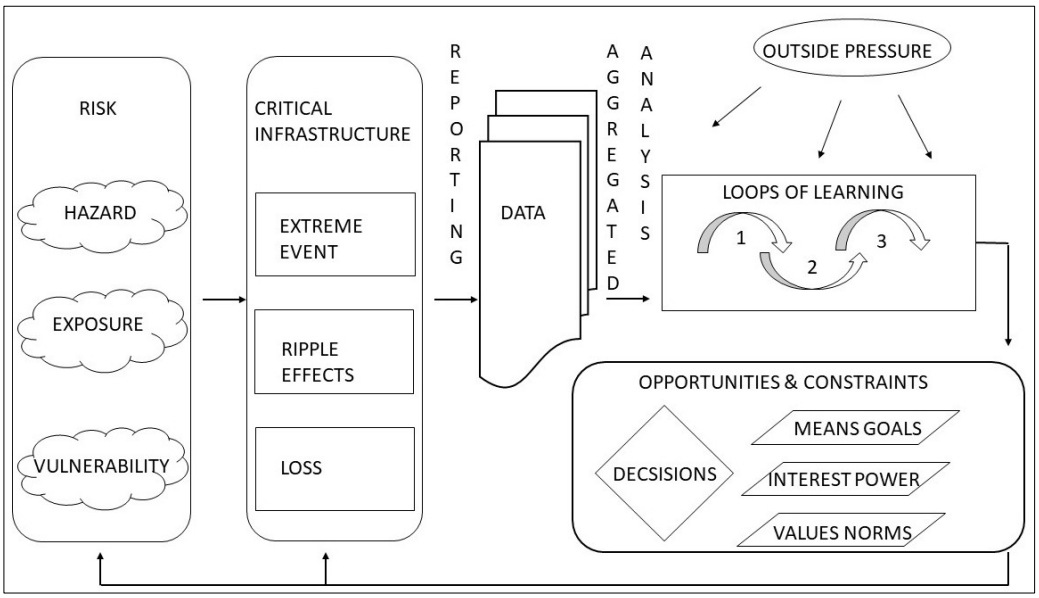

Figure 7: Contextual model applied to review articles shows that all signs of possibilities for facilitating organizational memory are there, if certain conditions are met. In the model, these conditions are shown as opportunities and constraints (lower right hand box).

7 Discussion

Land infrastructure is the backbone of a prosperous society, and therefore important to protect and make more resilient. A resilient, critical infrastructure has both functionality and structures that can withstand outer exposure and pressure. It is, in other words, important to understand how dependencies may hamper adaptive handling of issues related to natural hazards caused by climate change. In this respect, learning and knowledge sharing are enablers of infrastructure resilience.

7.1 Public-Private Partnership (PPP) and Lessons Learned

In Papers I, II & III, dependencies between actors are clearly revealed. These dependencies exist in response and recovery phases, and in aspects of feeding information and experience back to the organization (STA), especially in the relation to tenderers. Respondents at STA were concerned that feedback incentives were weak and not always prioritized. This concern may be a key issue to address if feedback and learning are seen as methods for lessons learned. Lessons learned are seen as methods for change and development The implication is that STA might have to promote different approaches to feedback and sharing of information in future tenders. Further, concerns were raised over retirements that would affect future operations negatively since personal relationships among tenderers and personnel from STA would fade. This is a concern related to human resources that can affect the outcome of how resilient and adaptive infrastructure networks are to be established.

Today, many PPPs are built on previous long-lasting relationships, since the former Swedish Road Administration (Vägverket) and Railway Administration (Banverket) employed many tenderers before the later STA was constituted. These relationships were identified by the project leaders at the STA as an advantage since the actors have a mutual understanding of problems and solutions.

Still, incentives for feedback seem to be rather weak, even if these are outlined in tenders. The reason for this problem may be that employees have stronger ties with their own organization and may be reluctant to share knowledge with others, for instance, STA. The reason can also be

related to the parallels of the organizational feedback mechanisms described in Paper I. This constraint of parallels may lead to weaker knowledgebase for future handling of extreme events and possible development of resilience. Feedback mechanisms are also a matter of governance, and how top managers use the provided information, and how experiences are aggregated, analyzed and implemented in the organization. Scholars assert the necessity of communicating and using experiences in practice by actually providing report systems that work. Respondents stated that there was a lack of communication on how and where their input was used, and if it was used at all. Respondents (Paper III) were critical of how their previous feedback seemed to have disappeared and not been used and also expressed disappointment with lack of information on how and when their feedback was used. Further, scholars argue strongly for a culture that provides resources to disseminate, analyze and discuss experiences and conclusions drawn. For establishing a trustworthy culture, and for feedback and learning to evolve, these issues are important to comprehend (Dekker, 2016; Dekker & Nyce, 2014; L. Field, 2017; Heikkila & Gerlak, 2013; Le Coze, 2013; Leveson, 2011; Viglione et al., 2014).

7.2 Industrial Investigation Methodology and Lessons Learned

Paper I shows that established industrial investigation methodology can be useful for investigating natural hazard events. The strongest reason is that these methods are well known and established. In an administration like the STA where technical aspects are relevant, these investigation methods are well understood, which are important in establishing or expanding issues related to seeking root causes of events.

These well-established investigation methods are effective in finding aspects of technical origin. Often, investigations are halted when technical flaws are found, which implies that organizational aspects are less relevant to these methods. This can be a challenge for investigators and the organizations, since investigators need to try to address other aspects than only finding technical aspects. By applying a sociotechnical perspective such as AcciMap, which is used in Paper I, root causes of organizational origin may be detected: as in regulations, incentives for feedback mechanisms, and communications between different levels of the organization.

In the context of natural hazards, issues of the traditional boundaries of investigations may be challenged by various questions such as: How is the environment affected and what implications will an event have on society? What are the cascading effects of natural hazards affecting multiple areas and sectors simultaneously, and how is that treated in the investigation and in the pursuit of root cause? Such questions may reveal and illustrate aspects that need to be addressed.

Presently, STA aims for robustness instead of resilience, which indicates emphasis on strengthening the technical aspects of the infrastructure and paying less attention to non-structural strategies. In short, this means managing risks with emphasis on strengthening physical capacities. Findings in the cases reveal a preference for bouncing back to a previous state, rather than bouncing forward which lessons learned could result in. Bouncing back is manifested in respondents' statements that most types of damage to systems and structures need to be maintained and swiftly reconstructed to their original state, indicating less incentives for ensuring a more resilient protection of functionality against future hazards (Paper II). This is of significance in relation to lessons learned. Without strong incentives for sharing experiences, the possibilities to make aggregated analyses may be weak. Further, this approach may not lead to lessons learned but rather to the organization staying within its comfort zone.

Learning is often circular, taking place in smaller groups and teams, where tacit knowledge may be discussed and incorporated if suitable to the situation (Heikkila & Gerlak, 2013). This can be described as making sense of experiences, and discussing and developing an understanding of issues. It could also lead to biases obscuring changes. Sometimes the processes of tacit knowledge sharing may seem rather ad hoc, with less strong incentives for sharing of knowledge and experience but the members of a team and organization may see fit to share, discuss and change how issues are dealt with (Paper III). Even so, learning in an organizational setting needs to be established through steering signals and incentives (Maslen, 2015; Stemn et al., 2018). Without incentives, opportunities for change may be overlooked. In a longer perspective, the organization may not continue to prosper, be competitive, efficient or able to solve targeted goals.

7.3 Collective Learning in Organizations

Sharing experience and knowledge requires availability of information. Data availability, reporting systems – both of improper use of these systems – and inadequate messages from management on the urgency to report are some major constraints mentioned by scholars. This includes the importance of reporting daily operations that might seem to be near misses, or incidents, for that matter. It is, and has been, argued by some scholars that acceptance of normality of near misses and incidences may develop into major events. Nevertheless, if data, reports and aggregated analysis are used for being proactive, the collective may learn to behave differently and change their views of matters. Other scholars propose the use of positive reinforcement as means of establishing a culture in which reporting and discussing matters would probably lead to positive notions of changes within the organization (Hollnagel et al., 2008; Rosness et al., 2016). Learning is also part of individual and team capacity to acknowledge and incorporate new or different information in their own understanding of problems and solutions to make sense of their experiences. It is also about having capacities and abilities to assimilate their own experiences into already existing frames and knowledge (Heikkila & Gerlak, 2013). This view rests on the notion that individuals, teams and their organization have a common interest in the mutual benefit of all, including the opportunity for individuals and teams to be part of successful innovations in the organization. This idea is challenged by the perceptions of power relations in organizations and society. Some individuals have the opportunity to take decisions, to make plans and change the organizations, while the greater part of employees in an organization does not have this power but are rather followers. This is even more prominent when looking at how organizations are asked to cooperate and collaborate across their borders.

Since society is a complex and integrated entity, in which many different interest groups and ideas work together, this results in both opportunities and constraints in the way knowledge sharing and learning are manifested. In a rapidly changing world with many loosely connected systems, coordination and integration are required for both decision-making and control mechanisms (Hovden et al., 2011; Rasmussen, 1997), and governance aspects are crucial to enhancing efforts to build a more resilient society. In a multifaceted world of many actors working together, there are many aspects of constraints regarding the flow of information and decision-making. These barriers can be both explicit, e.g. goals and responsibilities that make sharing

impossible, and implicit, e.g. power, values, cultures and norms in the hierarchy of each organization that impede sharing (Brown et al., 2016; Dekker & Nyce, 2014; L. Field, 2017; Le Coze, 2013; Maslen, 2015; McFadgen & Huitema, 2017; Stemn et al., 2018). The challenges involved in the tentative contextual model are discussed in Paper III. Individuals, teams and organizations may have similar understanding of goals, and still differences may be identified in a contextual model of learning. These differences may be the differences in means and goals between organizations that depend on each other, were values, attitudes, culture and norms influences the outcome of collaborations and cooperation cross-border.

Complexity in society and in the governance of organizations influences most relationships between actors. Most relationships and responsibilities of different actors are divided and often monitored by the few involved, which makes a full understanding of issues related to the steering of an organization very difficult to reach, including full appreciation of values, culture, norms and attitudes (Le Coze, 2013). Interaction and global feedback and feedforward loops are suited for organizations, and may contribute to expanding the knowledgebase of organizations. These loops may be ad hoc and simultaneous, as Heikkila and Gerlak (2013) point out. Many feedback loops are unintended as in voicing tacit knowledge in a smaller trusted group or team. This voicing of experience may be a starting point for reflection and discussions of tacit knowledge, which may lead to collective memory of knowledge and changes of cognition.

Incentives given by the management have been pointed out as crucial for building a collective memory (Drupsteen & Guldenmund, 2014; Le Coze, 2013; Stein, 1995; Stemn et al., 2018). The prospects of building a knowledgebase for a whole organization are rather bleak without explicit management involvement and available resources. Some of the constraints relating to bias and reluctance, as individuals often see their knowledge as an asset and are unwilling to share (Paper II), which reduces the possibility to build a stronger coherent society. Further, the constraints related to difficulties in the understanding of dependencies across organizational and national borders are important to shed light on. The constraints of high-level management to recognize the importance of incentives, and to work cross-border, both long- and short-term, may have significant impact on the outcome of DRR, DRM and CCA actions. Findings in Paper III may serve as examples of some assumed constraints that may taint future feedback mechanisms and possibilities to build more adaptive and resilient structures. A local and heavy snowfall, hard winds and avalanches affected businesses both at

local, national and international arenas, and the cascading effects on local, national and international stakeholders were recognized by the respondents. In this case the respondents were aware of previous measures taken for protecting the infrastructure from negative impact due to climate change related weather events. The respondents were aware of and discussed the cost of delays and damages to the wider society, while the response to extreme weather events was to install or enhance technical solutions and devices. In this case, technical solutions were upgraded and seemed to be the quick and easy response to future predicaments.

Another barrier to overcome, if the goal is a more adaptive and resilient society, is to recognize that climate change is ongoing. By acknowledging changes in climate, the transfer of experience and feedback loops may become an even stronger tool for adaptive measures and proactive efforts. Misunderstanding and misinterpretation of terminology regarding climate change and (climate change) adaptation (CCA) in the DRR efforts are evident (Paper II) (Hagelsteen & Burke, 2016; Otoo, Agapitova, & Behrens, 2009). Recognition of the ongoing change is necessary for establishing a proactive agenda for societal actors. Respondents both recognized and downplayed the significance of climate change (Paper II). In Paper III the STA respondents were aware of the climate change and its effect on the critical infrastructures and the cascading effects that extreme events may have on the critical infrastructure, while tender respondents (Paper II) seemed to downplay the significance of climate change and effects. Rather, their own abilities and capacities were highlighted as being sufficient to meet extreme events.

7.4 Learning and Adaptation

Two case studies in this thesis reflect downplay of climate change, along with weak interest in discussing climate as a root cause of damage (Papers II & III). The understanding among the respondents displays weak incentives for changing cognition and behavior towards adopting a proactive adaptive approach related to maintaining the functionality of critical infrastructures. Further, arguments that climate is an ”ongoing thing”, and nothing to be concerned about were expressed by the respondents, which implies that feedback on drawn experiences is scarce. This is an issue to be discussed and addressed by the head of the organization (STA in this case) if knowledge sharing and lessons learned are recognized as important and relevant for building

resilience. It was further shown that the respondents have a great deal of experience and know-how in handling extreme weather situations (Paper II), and that they have confidence in their own capacities and abilities to address climate change. Still, the understanding of climate change seems to be superficial, and if understood, the context is local. This should not be dismissed as a failure; rather most learning incentives may be implemented in the local team context, where the team members can discuss, disseminate and reflect on experiences and actions taken in a safe and secure environment. Such reflection may lead to different insights and knowledge development, and to changed cognition and behavior such as improved processing of conceptual schemes, better understanding of information, and changes in mental frames and references. If successful, these smaller local changes may affect the whole organization because if some change in cognition and behavior, others may follow suit (Heikkila & Gerlak, 2013). Biases within the team may impede changes in cognition and behavior since changes may threaten positions and status or even the work itself. If the biases are strong, there may be development of groupthink among the team members, which may lead to less reinforcement for decisions and possibilities to prosper.

7.5 Loops of Learning

Single loop feedback works within an existing framework, assumptions, values and principles (Bos, Brown, & Farrelly, 2013; Tosey, Visser, & Saunders, 2012). Single loop learning is the most common style of learning which deals with correcting first order errors, and is seen as quite instrumental (Argyris, 1999). Findings in the papers are foremost instances of single loop feedback mechanisms, both in processes and products of learning (Heikkila & Gerlak, 2013).

Double-loop learning deals with more than first order error correction by challenging the underlying assumptions, goals and values set for the organization, but also theories in use, and can therefore change outcomes (Argyris, 1999). It is important to understand that double loop learning relies on interdependent actors with capacities to challenge existing frameworks (Bos et al., 2013). This is an important prophecy, which can be interpreted as an incentive for managers and leaders to actually work for change. If so, why should the leaders challenge a system through which they were promoted, instead of continue on the already mapped out path? It is crucial to understand

this dilemma. Change may not come about even if the opportunity is there. Change may lead to less influence and power – resulting in no change.

Findings show that there is an understanding of the importance of changing behavior, especially as declared at top hierarchical levels, and in regulations from national and international levels (European Council, 2008; Proposition 2016/17:21; Regeringen, 2018) Triple loop learning goes beyond previous frames, and challenges the whole systems of underlying protocols (Argyris, 1999). Triple loop learning involves the same re-evaluation of assumptions and models as double loop learning, but takes it one step further through considering altering the rules for decision-making and making fundamental changes in the governance systems, as well as in the ways in which individuals behave in the organization. Triple loop learning is, according to Argyris (1999), very hard to achieve since it challenges core behavior, values, assumptions and power structures. Still, triple loop learning or the transformative way to change is often an organizational goal. This goal could be a wish to be better at handling changes but not necessarily understood as revolutionary since most organizations strive to maintain well-established goals, cultures and values. Therefore, the argument can be that most organizations are content with single and double loops of learning within the collective learning framework.

8. Contributions and Conclusions

How well do society and organizations make use of lessons learned? Can organizational memory actually be build? Some scholars argue that routines, rules, and procedures are part of an organization's memory. If so, how does this work in a more interrelated world where organizations and nations have to work cross-border? This is particularly intriguing when considering critical infrastructures (CI) and society's dependency on functionality of these systems.

I would like to think that this thesis contribute to an increased understanding of the opportunities – that actually are there – and the manifold constraints on how we can learn and share from experiences. There is still a great need for future research on the subject. I think it is necessary to understand the many opportunities and constraints involved in the evermore-growing interdependencies in the modern world in terms of how these interdependencies affect knowledge sharing, how lessons learned in one context can actually contribute to a larger arena, and somewhat different context(s).

I believe that society should try to ask questions on where we stand regarding sharing lessons. How can contributions to a growing knowledgebase be facilitated? Are there incentives for this? If not, how may change of incentives come about?

I also believe that society should try to consider not to use the concept of transformative (revolutionary) thinking in changes. I think that individuals (and thereby also society) are more comfortable with transitions and incremental changes, and therefore such changes would be more acceptable to make. By making changes in the use of concepts, it may easier to address changes differently and, in a longer perspective, perhaps become more successful in lessons learned and implementing these in operations and practices. Both in the STA and in other organizations.

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Organizational Lessons Learned

The Sendai Framework for Action (2015) and the agreement in Paris in 2015 (COP, 2015) were historic manifestations that society has to work with both mitigation and adaptation to achieve a reduction of the adverse effects of climate change. One way to achieve adaptation is through the integration of present coping strategies. A first step is to study the existing processes and routines that support short-term coping. This thesis targets different aspects of knowledge sharing and learning as a strategy for building adaptive and coping capacity. The Swedish Transport Administration provides cases of extreme events for the studies. Paper I deals with the possibility to apply industrial accident investigation methods to an extreme weather event and get useful insights into underlying root causes. Paper II displays the intra- and interrelated patterns that exist in public-private partnerships (PPP) in Sweden. Paper II describes parallel systems with infrequent overlaps regarding lessons learned. Paper III discusses collective learning approaches, in which obstacles and opportunities are identified. Furthermore, incentives to bounce forward in the aftermath are discussed from a collective learning approach. Paper IV reviews the concept of organizational memory building as a means for change.

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