Exploring the Railway System from a Risk Governance Perspective

Cedergren, Alexander

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LUND UNIVERSITY

PO Box 117
221 00 Lund
+46 46-222 00 00

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Alexander Cedergren

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Alexander Cedergren

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Abstract
The objectives of this thesis are to identify challenges to risk governance in the Swedish railway system, and to provide knowledge and means to address these challenges. Three case studies are presented in the thesis, including two studies of the process involving accident investigation and implementation of recommendations, and one study of risk-related decision-making at the design stage of Swedish railway tunnel projects. The findings show that important challenges to risk governance in the Swedish railway system involve problems related to diverse framings of risk, dispersed responsibility, and fragmentation of the risk governance process. In order to address problems related to the fragmentation of the risk governance process, a conceptual framework for studying and analysing risk governance from a design perspective is developed. The thesis also presents a method for vulnerability analysis of the railway system, which takes both structural and functional aspects into account, and includes three complementary perspectives of vulnerability.

Key words
risk governance, railway, framing, accident investigation, implementation, vulnerability, resilience, critical infrastructure

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Exploring the Railway System from a Risk Governance Perspective

LUND UNIVERSITY

Alexander Cedergren

Doctoral Thesis

Supervisor
Professor Kurt Petersen, Department of Fire Safety Engineering and Systems Safety, Faculty of Engineering, Lund University

Co-Supervisor
Associate Professor Henrik Tehler, Department of Fire Safety Engineering and Systems Safety, Faculty of Engineering, Lund University

Assessment Committee
Professor Jan Hovden, Norwegian University of Science and Technology (NTNU), Norway (Opponent)
Professor Preben Lindøe, University of Stavanger, Norway
Professor Uday Kumar, Luleå University of Technology, Sweden
Associate Professor Olof Samuelsson, Lund University, Sweden

Department of Fire Safety Engineering and Systems Safety
Lund University, P.O. Box 118, SE-221 00 Lund, Sweden
Lund University Centre for Risk Assessment and Management (LUCRAM)
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Summary

In recent decades, the Swedish railway system has faced substantial deregulations. As a result, management of risk is often carried out in settings involving multiple stakeholders having various roles, mandates, and viewpoints on risk, and where no single stakeholder has the superior authority. In order to manage risks in this type of multi-actor setting, the traditional elements of risk assessment, management and communication have been described as too narrow. In addition to these elements, the literature in the emerging field of risk governance emphasises the need to also take the social, institutional, legal, and economic contexts into consideration.

With this background as a point of departure, this thesis explores challenges to risk governance in the Swedish railway system, and presents means to address these challenges. The term risk governance is used in a broad sense in the thesis. Rather than restricting the term to activities related to managing risks in a forward-looking perspective, it is also used to denote processes related to accident investigation and implementation of recommendations.

The findings include three main challenges to risk governance. The first challenge relates to dispersed responsibility, and refers to situations where the various stakeholders involved in the governance of risk have limited awareness, or diverse views, of each other's roles and mandates. The second challenge to risk governance involves a fragmentation of the risk governance process. This challenge may arise when one step in the risk governance process is not fully connected to subsequent steps. The third challenge to risk governance relates to situations where the different stakeholders involved in decision-making over risks have diverse framings of the risk in question.

As a result of diverse framings of risk, controversies among the different stakeholders are likely to arise. This is often the case in risk-related decision-making at the design stage of Swedish railway tunnel projects, where power relations and precedents in many cases influence the outcome of the decision-making process. Moreover, due to the prominent role played by local stakeholders (municipal authorities) in these projects, substantial focus is directed at local matters of each railway tunnel. Because of this, the importance of each tunnel from a regional or national perspective, such as the railway system's resilience to failures, receives less attention.

In order to proactively identify vulnerabilities of the railway system, and thus, to provide opportunities to strengthen the system's resilience, a simulation-based method

for vulnerability analysis of the railway system is presented. This method includes the creation of both a structural and a functional model of each of the seven sub-systems comprising the railway system, and these models are linked by so-called dependency edges. The method enables analysis of vulnerabilities from three different perspectives: global vulnerability analysis, critical component analysis, and geographical vulnerability analysis.

The problem related to fragmentation of the risk governance process is addressed by developing a conceptual framework that explicitly links the way risks are handled at the micro-level to aspects at the macro-level. The framework is influenced by design science, and it allows descriptive, evaluative, as well as normative approaches to analysing risk governance processes.

Finally, the thesis investigates the way accidents are framed in accident investigation reports. The results reveal that a majority of attributed causes in the accident investigation reports analysed in this thesis are identified at the micro-level. This means that a basis for learning mainly exists for factors at this level. Since the findings indicate that investigators are inclined to focus on areas of their own expertise, the importance of providing a diversity of competences among investigators, as well as the value of exploring the potential benefits associated with multi-modal accident investigation boards, is highlighted.

Sammanfattning (in Swedish)

Under de senaste decennierna har det svenska järnvägssystemet genomgått omfattande avregleringar. Som följd av detta sker hanteringen av risker ofta i kontexter som innefattar flera intressenter med olika roller, mandat och synsätt på risk, och där ingen enskild intressent har överordnade befogenheter. Enligt litteraturen inom det framväxande forskningsfältet om riskstyrning (eng. ”risk governance”) är de traditionella elementen bestående av riskvärdering, riskhantering och riskkommunikation för snäva för att på ett adekvat sätt hantera risker i denna typ av sammanhang. Utöver dessa beståndsdelar är det även nödvändigt att ta de sociala, institutionella, legala och ekonomiska kontexterna i beaktning.

Med denna bakgrund som utgångspunkt utforskar denna avhandling utmaningar med riskstyrning i det svenska järnvägssystemet, och presenterar sätt att hantera dessa utmaningar. Termen riskstyrning används i vid bemärkelse i avhandlingen. Snarare än att begränsa termen till aktiviteter relaterade till hantering av risker i ett framåtblickande perspektiv används även termen för att inkludera processer som har att göra med olycksutredningar och implementering av de efterföljande rekommendationerna.

Resultatet visar på tre huvudsakliga utmaningar för riskstyrning. Den första utmaningen handlar om utspridd ansvarsfördelning, och syftar på situationer där de olika intressenterna som är inblandade i styrningen av en viss risk har begränsad kännedom, eller olika uppfattningar, om varandras roller och mandat. Den andra utmaningen innefattar en fragmentering av riskstyrningsprocessen. Denna utmaning kan uppstå när ett visst steg av riskstyrningsprocessen inte är fullt sammankopplat med efterföljande steg. Den tredje utmaningen innefattar situationer där de olika intressenterna som är involverade i beslutsfattande kring risker har olika synsätt (eng. ”framings”) på den aktuella risken.

Som ett resultat av olika synsätt på risk kan spänningar mellan de olika intressenterna uppstå. Resultatet från avhandlingen visar att detta ofta är fallet vid beslutsfattande om risker under projektstadiet av svenska järnvägstunnlar, där maktrelationer och prejudikat i många fall påverkar utfallet av beslutsprocessen. På grund av den framträdande rollen som kommunala aktörer har i dessa projekt så riktas stort fokus på de lokala aspekterna av varje tunnelprojekt. Därmed ges mindre uppmärksamhet åt varje tunnels betydelse ur ett regionalt eller nationellt perspektiv, såsom järnvägssystemets resiliens.

För att proaktivt identifiera sårbarheter i järnvägssystemet, och på så sätt skapa möjligheter för att stärka systemets resiliens, presenteras en simuleringsbaserad metod för sårbarhetsanalys av järnvägssystemet. Metoden innefattar framtagande av både en strukturell och en funktionell modell för vart och ett av de sju delsystem som tillsammans bildar järnvägssystemet, samt beroenden mellan dessa system. Metoden möjliggör analys av sårbarheter från tre olika perspektiv: global sårbarhetsanalys, analys av kritiska komponenter, och geografisk sårbarhetsanalys.

Problem relaterade till fragmentering av riskstyrningsprocessen hanteras genom att utveckla ett konceptuellt ramverk för att analysera riskstyrningsprocesser från ett designperspektiv. Detta tillvägagångssätt är influerat av designvetenskap och möjliggör deskriptiv, utvärderande och normativ analys av riskstyrningsprocesser.

Slutligen visar avhandlingen att synsättet på risk även spelar en betydande roll vid olycksutredningar, eftersom valet av faktorer att beskriva som orsaker till en olycka påverkar vilka lärdomar som dras. De olycksutredningsrapporter som analyseras i denna avhandling visar att majoriteten av de beskrivna orsakerna kan identifieras på mikronivån. Resultatet indikerar även att utredarna är benägna att fokusera på områden som ligger nära den egna expertisen, och därför betonas vikten av att sträva efter en mångfald av kompetenser hos utredarna samt att aktivt utforska de potentiella fördelarna som en multimodal haverikommission möjliggör.

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Lund, October 26, 2013

Alexander Cedergren

1 Introduction

Our modern society is dependent on a number of critical infrastructure systems, including for example electric power, telecommunications, water supply, and transportation (Almklov & Antonsen, 2010; MCEER, 2005; Murray & Grubesic, 2007; Rinaldi, Peerenboom, & Kelly, 2001). In recent decades, these systems have become increasingly interconnected, which has resulted in greater efficiency under normal operation, but also increased vulnerabilities in the face of failures or disturbances (Hills, 2005; IRGC, 2006a). Since a failure affecting one system can propagate more easily to other systems (Amin, 2000; Boin & McConnell, 2007; Little, 2002, 2004), the crises that result are not confined to sectorial, jurisdictional or national borders, but have become increasingly trans-boundary in nature (Ansell, Boin, & Keller, 2010; Boin & Lagadec, 2000).

In parallel with the increasing number of interdependencies between various systems in society, the design, management, operation and maintenance of many of these systems is divided between a larger set of stakeholders (Almklov & Antonsen, 2010; de Bruijne, 2006). Due to this institutional fragmentation of many critical infrastructures (de Bruijne & van Eeten, 2007), the management of risks facing these systems often need to be carried out in settings involving a variety of stakeholders, where no single actor has superior authority. As a result, multiple legitimate viewpoints on risks co-exist, and different interpretations of whether risks are tolerable or not can give rise to significant debate and controversy (van Asselt & Renn, 2011).

In order to manage risks in this type of multi-actor setting, the traditional elements of risk assessment, management and communication have been described as too narrow (Renn, Klinke, & van Asselt, 2011). In addition to these elements, the literature in the emerging field of risk governance emphasises the need to pay attention to the legal, economic, social and institutional contexts in which risks are managed (Hermans, Fox, & van Asselt, 2012). In this way, the field of risk governance is particularly focused on management of risks in settings involving multiple players with diverse roles and responsibilities. In the context of critical infrastructures, risk governance has been defined as "the totality of players, rules, conventions, processes, and mechanisms concerned with how relevant risk information is collected, analysed and communicated and management decisions are taken" (IRGC, 2006b: p. 65).

In this thesis, risk governance in the Swedish railway system is explored. The trends involving increased institutional fragmentation and growing interdependencies are clearly visible in this domain. While the railway system is strongly dependent on other infrastructure systems, such as power supply and ICT[1] systems (IRGC, 2006b), it also constitutes a vital system for many other sectors in society. Since railways are used by people to go to work as well as by industry for transportation of hazardous materials and just-in-time delivery of important goods, failures in the railway system can have immediate and far-reaching consequences, both in terms of human loss and societal impact (IRGC, 2006b; Laperrouza, 2009). At the same time, the responsibility for different functions in the Swedish railway system has become increasingly fragmented, since the sector has faced considerable deregulation over the last decades (Alexandersson, Hultén, Nilsson, & Pyddoke, 2012; SOU 2008:92). What was once a fully state-owned and state-operated sector has been transformed into a deregulated market in which private actors compete over contracts on maintenance and train operation (Bårström & Granbom, 2012; SOU 2008:92; Swedish Transport Administration, 2011). As a result, risk-reducing activities are in many cases taken in settings involving a variety of players with diverse roles and responsibilities. Despite the importance of understanding the way risks are managed in this type of multi-actor context, our knowledge about effective measures to deal with risks and vulnerabilities at the societal level are far less than our knowledge and tools to analyse risk at the individual and organisational levels (Olsen, Kruke, & Hovden, 2007). With this background in mind, the objectives of this thesis are formulated in the following way:

> *The objectives of this thesis are to identify challenges to risk governance in the Swedish railway system, and to provide increased knowledge and means to address these challenges.*

1.1 Key Stakeholders of the Swedish Railway System

As described in the previous section, the Swedish railway system has faced substantial deregulations in the last decades. In this section, a few of the most important reforms and key stakeholders of the Swedish railway system are briefly summarised (for a more detailed account, see e.g. Alexandersson et al., 2012, and SOU 2008:92).

In 1988, responsibility for railway infrastructure investment and management was separated from train operation. The Swedish Rail Administration (Banverket) was established as the infrastructure provider, while SJ was responsible for train operation. Subsequent reforms include the transfer of train traffic control from SJ to the Swedish Rail Administration (Banverket), the opening of the freight train market for

[1] ICT refers to information and communication technology (IRGC, 2006b).

competition (in 1996), and a few years later, privatisation of maintenance and real estate. The market for passenger transport has been gradually opened for entry, and the most recent reform includes the opening of passenger transport to full competition, starting in 2012, which enabled even more operators to entry the market.

In 2004, the Swedish Rail Agency (Järnvägsstyrelsen), with responsibility for safety issues, market monitoring and regulation, replaced the previous Railway Inspectorate (Järnvägsinspektionen). In 2009, this agency (sometimes referred to as the safety authority) was merged with similar agencies into the Swedish Transport Agency (Transportstyrelsen). In the following year, the Swedish Rail Administration (Banverket) was merged with the Swedish Road Administration (Vägverket) into the Swedish Transport Administration (Trafikverket). In addition to these public bodies, the Swedish Accident Investigation Authority (Statens Haverikommission) holds a central role in the Swedish railway system as the independent body responsible for investigation of major incidents and accidents. This body was established in 1978, and the railway branch was established in 1990.

1.2 Thesis Outline

This thesis is organised as follows. In Chapter 2, the research objectives described in the first section are iterated and more specific research questions are formulated. In Chapter 3, the theoretical framework underpinning the thesis is outlined, and in Chapter 4 the methods and materials are described. The research contributions are presented in Chapter 5 and these contributions are discussed in Chapter 6, where the quality of the research as well as suggestions for future studies is presented. Finally, conclusions from the thesis are presented in Chapter 7. In the Appendix, the five research papers (which are listed in the next section) are included.

1.3 Appended Publications

I Cedergren, A. (2013). Designing resilient infrastructure systems: a case study of decision-making challenges in railway tunnel projects. *Journal of Risk Research, 16*(5), 563-582.

II Johansson, J., Hassel, H., & Cedergren, A. (2011). Vulnerability analysis of interdependent critical infrastructures: case study of the Swedish railway system. *International Journal of Critical Infrastructures, 7*(4), 289-316.

III Cedergren, A., & Petersen, K. (2011). Prerequisites for learning from accident investigations - A cross-country comparison of national accident investigation boards. *Safety Science, 49*(8-9), 1238-1245.

IV Cedergren, A. (2013). Implementing recommendations from accident investigations: a case study of inter-organisational challenges. *Accident Analysis & Prevention, 53*, 133-141.

V Cedergren, A., & Tehler, H. (Submitted paper). Studying risk governance using a design perspective. *Submitted to an international peer-reviewed journal.*

1.4 Related Publications

- Cedergren, A., 2014. A case study of challenges facing the design of resilient socio-technical systems. In C. Nemeth & E. Hollnagel (Eds.), *Resilience Engineering in Practice: The Road to Resilience.* Farnham: Ashgate Publishing Limited.

- Hummerdal, D., Wilhelmsson*, A., & Dekker, S. W. A., 2013. Learning from Failure. In J. D. Lee & A. Kirlik (Eds.), *The Oxford Handbook of Cognitive Engineering* (pp. 404–412). New York: Oxford University Press.

- Cedergren, A., 2011. Challenges in designing resilient socio-technical systems: A case study of railway tunnel projects. In E. Hollnagel, E. Rigaud & D. Besnard, (Eds.), *Proceedings of the fourth resilience engineering symposium* (pp. 58-64). Presses des MINES, Sophia Antipolis, France.

- Cedergren, A., & Petersen, K., 2010. Learning from accident investigations – A cross-country comparison. In *Proceedings from "The 10th International Probabilistic Safety Assessment & Management Conference" (PSAM 10)*, Seattle, USA.

- Wilhelmsson*, A., & Petersen, K., 2009. Learning from failure - Research initiatives towards improving resilience of the Swedish railway system. In *Proceedings from "The International Railway Safety Conference" (IRSC)*, Båstad, Sweden.

- Wilhelmsson*, A., & Johansson, J., 2009. Assessing response system capabilities of socio-technical systems. In *Proceedings from "The International Emergency Management Society" (TIEMS)*, Istanbul, Turkey.

* The author has changed surname from Wilhelmsson to Cedergren

2 Research Objectives and Research Questions

As described in Chapter 1, the objectives of this thesis have been formulated in the following way:

> *The objectives of this thesis are to identify challenges to risk governance in the Swedish railway system, and to provide increased knowledge and means to address these challenges*

In order to meet these objectives, more specific research questions have been formulated[2], which have been addressed in the appended papers. These papers were initiated sequentially, as preliminary results from the various research activities were obtained. In this way, most of the papers are linked to each other, which means that the rationale behind each paper is best understood in the light of the research process. It also means that the appended papers are presented in the order they were initiated, although this does not correspond to the order in which they were submitted or published. In Figure 1, the chronology of the research process is presented. As shown in this figure, preliminary findings from Paper I (which was not completed until after Papers II and III) gave rise to ideas underlying Papers II and III. Subsequently, Paper III triggered the ideas that led to Paper IV, which in turn gave rise to the research question underpinning Paper V.

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[2] In the appended papers, relatively broad aims or objectives are formulated, rather than explicit research questions. These aims or objectives have here been rephrased into specific research questions.

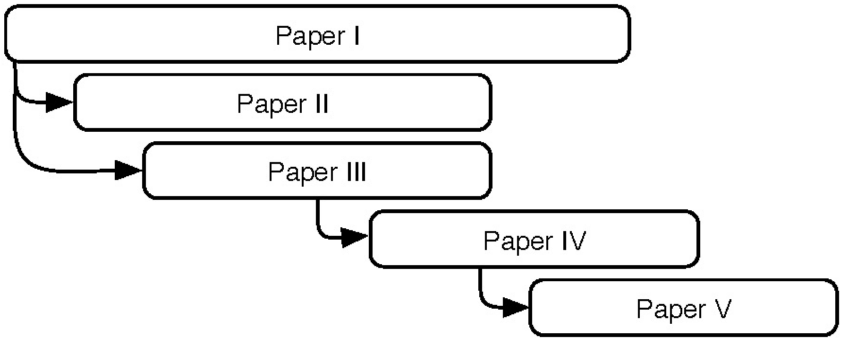

Figure 1: Schematic outline of the chronology of the research process

Paper I is the result of the first research activity aimed at identifying challenges to risk governance in the Swedish railway system. In this explorative paper, decision-making at the design stage of railway tunnel projects was studied. Numerous aspects need to be taken into account at the design stage of these projects. For example, railway tunnels require a very large capital investment; they are technically challenging to construct; they need to be able to withstand various threats over a considerable lifetime; they represent a hostile environment for evacuation in the face of emergencies, and; they constitute critical elements for the functionality of the railway system as a whole.

As a result of this wide variety of important considerations, several different actors with diverse roles and responsibilities are involved at the design stage in these projects. In this type of setting, the various actors often draw on different, but equally legitimate, knowledge bases in order to influence the process related to managing risk (Renn et al., 2011). As a result, disagreements and controversies may arise regarding different interpretations of risk assessment outcomes (van Asselt & Renn, 2011). The multiplicity of goals and perspectives to consider at the design stage of railway tunnels made this type of project interesting to explore from a risk governance perspective. This gave rise to the first research question:

> *1a) Does the multi-organisational setting characterising railway tunnel projects in Sweden give rise to challenges to risk-related decision-making? If so, what are these challenges?*

Since the railway system provides essential services to our society, failures to this type of critical infrastructure systems[3] have a potential to result in significant consequences to human health as well as the economy (de Bruijne & van Eeten, 2007; Little, 2004). In order to minimise these consequences, such systems need to be resilient to failures, i.e. they need be able to continue operations, or quickly recover to a stable state, after a major disturbance (McDaniels, Chang, Cole, Mikawoz, & Longstaff, 2008). This is recognised in the national Swedish strategy for protection of essential societal functions, which declares as its overall goal to provide society as a whole, including its critical infrastructures, with an increased degree of resilience (Swedish Civil Contingencies Agency, 2011). However, it is not evident to what extent this is achieved in practice, and what type of challenges this involves.

Due to the structural properties of the Swedish railway system and the substantial time for restoration required after serious accidents or disturbances affecting railway tunnels (such as fires or derailments), each tunnel represents a critical element of the railway system from a regional, and even national, perspective. This criticality of each tunnel calls for an analysis of whether the railway system's resilience was considered already at the design stage of railway tunnels, since opportunities to provide increased resilience to the railway system as a whole exist already at this stage. For this reason, the following research question was formulated:

> *1b) To what extent is the railway system's resilience to failures addressed at the design stage of railway tunnel projects in Sweden?*

Research questions 1a and 1b were addressed in Paper I. The findings from this paper, which will be more extensively presented in Chapter 5, were highly influential for the initiation of further studies. In particular, the results showed that the ways in which risks are framed play an important role for shaping the outcome of the process related to governance of risk. This insight provided the basis for research question 3 described later in this section. In addition, Paper I underlined the fact that failures to individual elements in the railway system (such as railway tunnels) may have significant consequences to the railway system's functionality at the regional and national levels. These types of vulnerabilities may not be identified if a local perspective of the railway system is adopted (i.e. a perspective where the system boundaries are drawn around individual elements, rather than seeing the role of these elements from a more holistic perspective). In order to increase the ability to address the way failures to critical

[3] An infrastructure system denotes a large-scale man-made system producing a continuous flow of essential goods and services (see e.g. IRGC, 2006b, for similar definitions). The view on what defines a *critical* infrastructure system is shared with Almklov and Antonsen (2010: p. 133), who remark that "an infrastructure is critical if its failure would lead to unacceptable human or economic consequences, and would impact societies' capabilities of rescue, response and recovery".

elements give rise to consequences for the system as a whole, there is a need to perform comprehensive and systematic analyses of vulnerabilities in the railway system (IRGC, 2006b). The descriptive study undertaken in Paper I was thus followed by a more normative research activity (presented in Paper II) with the aim of developing a method for analysing vulnerabilities in the railway system.

While a large number of methods for analysis of vulnerabilities in various types of networks have been presented in other societal domains, limited focus has been paid to developing these types of methods in the railway system (Peterson & Church, 2008). For this reason, a method that is specifically designed for vulnerability analysis of the railway system is needed. Several desired characteristics of such method can be identified. In particular, a method for vulnerability analysis of the railway system needs to be capable of taking interdependencies between various sub-systems into consideration, since the railway system is composed of a number of different coupled infrastructures. Since these different sub-systems have different functions, which in turn affect the overall service of the railway system, all sub-systems cannot be treated in the same way in such a method. Rather, the method needs to be capable of taking different functional properties into account. In addition, since infrastructure systems often are designed according to the N-1 criterion, i.e. to be able to withstand a single failure (IRGC, 2006b), this type of method should be capable of analysing scenarios involving two or more simultaneous failures. Finally, due to the complexity of the infrastructures, it is important to apply several perspectives of analysis in order to understand the vulnerabilities facing these systems (Murray, Matisziw, & Grubesic, 2008). This gave rise to the following research question, which was addressed in Paper II:

> *2) How can a method be developed that enables systematic identification of vulnerabilities of the Swedish railway system, with particular consideration of the following aspects:*
>
> - *Interdependencies between sub-systems,*
> - *Functional properties of sub-systems,*
> - *Multiple simultaneous failures, and*
> - *Multiple perspectives of vulnerability?*

As described above, Paper I demonstrated that the way risks are framed affects the way they are managed. This insight provided the basis for Paper III. While Papers I and II focused on processes related to identification of risks and vulnerabilities in a forward-looking perspective, i.e. through the use of risk and vulnerability analyses, an equally important source of risk identification comes from experience feedback (ESReDA, 2009). In the railway system, accident investigations conducted by the national accident investigation board constitute an important input to the process related to governance of risk. The way accidents are framed in these official reports, i.e. the factors that are attributed as causes to the accidents, affects what potentially will be learned and what risks that will be managed (cf. Catino, 2008; Hollnagel, 2008). Normally, investigators start by looking at events and conditions in the close proximity (spatially and temporally) of the accident scene. For example, these kinds of factors include the actions taken by individual operators in the time span immediately before the accident, or the functioning of various physical components (referred to as the micro-level). Gradually, more remote factors are brought into the analysis, such as organisational factors (the meso-level) or factors at the societal level, such as the regulatory conditions or the cross-organisational interplay (the macro-level). However, there are generally no guiding criteria for how far away in space and time from the "top event" one should look (Leveson, 2004). The lack of a definite "stop-rule" in accident investigations (Rasmussen, 1990) calls for an analysis of the way accidents are framed in accident investigation reports. This gave rise to the following research question, which was addressed in Paper III:

> *3) How much emphasis is placed on factors at different hierarchical levels (the micro, meso, and macro level, respectively) in official railway accident investigation reports, and what measures can be taken to change the focus of attention in such a way that it facilitates more effective learning from accidents?*

The official accident investigation reports analysed in Paper III provide valuable lessons to the railway industry. However, the investigation report itself is merely a first step in the process related to governance of risk. In order to reduce risk and improve safety, the recommendations in these investigations need to be followed by the required actions, i.e. they need to be implemented. While considerable research has focused on the challenges related to accident investigation and the methods adopted in this step, less emphasis has been paid to the challenges related to implementation of recommendations (Carroll & Fahlbruch, 2011; Lundberg, Rollenhagen, & Hollnagel, 2010). Since a number of different players are involved in the implementation of recommendations, this process is of particular interest from a risk governance perspective. This led to the following research question:

> *4) To what extent have recommendations from official railway accident investigations in Sweden resulted in implemented actions, and what challenges to implementation of these recommendations can be identified?*

The findings from Paper IV (which will be more thoroughly described in Chapter 5) underlined the importance of ensuring that different steps of the risk governance process[4] are connected to each other. While the activities taking place within each organisation may satisfy this organisation's individual goals and responsibilities, these activities may still lead to outcomes that are not optimal at the macro-level. For this reason, it is important to develop an approach that enables systematic analysis of the link between different activities in the risk governance process. This gave rise to the final research question:

> *5) How can a systematic approach for studying risk governance be developed that explicitly explores the link between the way risks are managed at the micro-level and aspects at the macro-level?*

The research questions outlined above are addressed in Chapter 5. Before these questions are answered, the theoretical framework underlying the thesis is described (in Chapter 3), and the methods and material used in the various studies are presented (in Chapter 4).

[4] The term risk governance process is here referred to as the set of actions taken in order to manage risk in contexts involving multiple stakeholders, where no individual stakeholder has predominant authority. IRGC (2006a) provides a generic model for such a process, which contains four phases: pre-assessment; risk appraisal; tolerability and acceptability judgment; and risk management.

3 Theoretical Framework

The theoretical framework underpinning this thesis lies at the intersection between several fields of research. Particular inspiration has been drawn from the field of risk governance, but a number of related concepts and fields of research (which will be outlined in the following sections) have also provided important points of departure. One of the most central terms of the thesis is the risk concept, and the chapter therefore begins by describing the way this notion has been interpreted.

3.1 Risk

The risk concept is central to many fields of research, including economics, psychology, political science, engineering, and sociology. This means that several different perspectives on risk can be found (Ben-Ari & Or-Chen, 2009; Möller, 2012), and there is no commonly accepted definition (Aven & Renn, 2009). The different perspectives on risk are based on different underlying assumptions (Jasanoff, 1998; Tjørhom, 2010). In engineering, a technical approach to managing risk has traditionally been used, which builds on the idea of risk as an objective function of probability and consequence (Renn, 1998). However, this viewpoint on risk has faced significant criticism, particularly from the social sciences, which typically rejects the view of risk as an objective fact (Bradbury, 1989). In contrast to the engineering view of risk, much social science research sees scientific knowledge as socially constructed. According to this tradition, risks are shaped by history, politics, and culture (Jasanoff, 1998). Moreover, many scholars emphasise the multidimensional nature of risk, which means that the concept cannot be reduced to a combination of probability and harm (Bradbury, 1989).

Before presenting the view of risk adopted in this thesis, it is essential to outline the ontological and epistemological positions taken. In ontological terms, this thesis builds on a view that there is a world existing independently of our perception of it. However, all phenomena in this world are not directly observable to us, and those aspects that are observable may in fact give a misleading picture of the phenomenon in question (see Marsh & Furlong, 2002). In this way, knowledge cannot be gained from sensory impressions and observations alone (see Blatter & Haverland, 2012). Moreover, the knowledge we derive from a specific observation is always mediated by the concepts and theories we use to analyse it, and accordingly, there is no way of describing an observation without interpreting it (see Marsh & Furlong, 2002). This view shares Kuhn's (1996) point that research is typically carried out within a particular paradigm, which affects the way each step of the research is conducted, and in turn, renders certain conclusions almost unthinkable. In epistemological terms, this thesis therefore takes a view of knowledge as a social and historical product, which is closely related to a specific culture or a specific point in time (see e.g. Robson, 2002). With this view, it is important to try to understand the perceptions and intentions of various actors, as well as the contexts of interaction (Blatter & Haverland, 2012). Since this thesis is particularly focused on exploring management of risk in multi-actor settings, a broad view of risk needs to be taken that allows different value-bases and different perspectives on the meaning of risk. For this reason, the concept of risk in this thesis has been defined in accordance with the viewpoint presented by Klinke and Renn (2002: p. 1071) as "the possibility that human actions or events lead to consequences that harm aspects of things that human beings value".

In the context of societal decision-making about risks, various approaches have been presented in which the inclusion of perceptions, values, and preferences have been combined with traditional techniques of risk management (see e.g. Klinke & Renn, 2002). In these types of approaches, social and political forces are used as a basis for setting priorities and determining the criteria for judging tolerable levels of risk, whereas technical assessments constitute an important input to quantify the extent of potential damage. Stakeholder involvement in decision-making over risk is a central tenet of these kinds of approaches (Jasanoff, 1998). In this way, the diverse framings of risks are acknowledged, at the same time as a systematic and transparent approach to decision-making over risks is advocated. Like the view adopted by Hermans et al. (2012), the view on risk management taken in this thesis thus recognises public values in their own right as an important input, without rejecting the value of technical approaches to risk management.

3.2 Risk Governance

Managing risks on the societal level requires collaboration between a variety of different stakeholders. This process, in which a multitude of actors (individuals, institutions, public and private bodies) manage risks, is referred to as risk governance (Renn et al., 2011). Although risk governance involves the traditional elements of risk assessment, risk management, and risk communication (Hermans et al., 2012), these components have been described as too narrow to deal with risks in modern systems (Renn et al., 2011). For this reason, the risk governance perspective extends these elements to a broader picture of risk by taking the social, institutional, legal, and economic contexts into consideration (Hermans et al., 2012). The concept of risk governance thus denotes "the totality of players, rules, conventions, processes, and mechanisms concerned with how relevant risk information is collected, analysed and communicated and management decisions are taken" (IRGC, 2006b: p. 65). In the multi-actor settings in which risk-related decision-making is performed, it is not uncommon that coordination and reconciliation are required between the diverse roles, perspectives and goals involved (IRGC, 2006a).

In this thesis, risk governance has been used as a theoretical lens for approaching activities related to management of risk in settings involving multiple stakeholders (public as well as private) with different roles and mandates, and where no single player has superior authority. An important aspect in adopting a risk governance perspective is therefore the need to take the multiplicity of roles and viewpoints into account for studying the ways that risks are handled. Moreover, it is important to emphasise that the concept of risk governance is used in a broad sense in this thesis. This means that the scope of the various case studies presented in the appended papers are not limited to activities related to managing risks in a forward-looking perspective, but also involves processes related to accident investigation and implementation. All of these activities are referred to as risk governance processes, since they represent multi-actor and multi-level settings in which risks are managed, and where none of the actors have predominant authority.

The concept of risk governance can be used both in a descriptive and a normative sense. The definition of the risk governance concept presented in the first paragraph of this section (which, in accordance with IRGC, 2006b: p. 65, denotes risk governance as "the totality of players, rules, conventions, processes, and mechanisms concerned with how relevant risk information is collected, analysed and communicated and management decisions are taken") has a clearly descriptive tone. However, according to Renn et al. (2011: p. 233), "risk governance is more than just a descriptive short hand for a complex, interacting network in which collective binding decisions are taken around a particular set of societal issues". One of the most influential writings on risk governance is the White Paper presented by the International Risk Governance Council (IRGC, 2006a), which includes a risk governance framework. This framework aims at providing "guidance for the development of comprehensive assessment and management strategies to cope with risks, in particular at the global level" (IRGC, 2006a: p. 11). This framework clearly marks the normative side of risk governance (see also Klinke & Renn, 2012, for another normative approach).

In this thesis, both uses of the concept (i.e. both descriptive and normative) are adopted. In the case studies presented in Papers I and IV, risk governance has been applied as a theoretical lens, and in this way, the concept has been used descriptively to focus on the way risks are managed in multi-actor and multi-level settings. In Paper V, a framework for analysing risk governance processes is presented, which draws significant influence from the area of design science. The aim of design science is "to develop knowledge for the design and realization of artefacts, i.e. to solve construction problems, or to be used in the improvement of the performance of existing entities, i.e. to solve improvement problems" (van Aken, 2004: p. 224). This means that design science offers a normative perspective in the sense that it deals with "how things ought to be" (Simon, 1969: p. 114). As a result of the inspiration drawn from design science in Paper V, the framework presented in this paper includes a normative side.

The term risk governance represents the application of the "governance" concept to the field of risk research. Governance is a widely used term in the policy sciences, and highlights the interaction between private and public actors at various societal levels. This process is typically described as non-hierarchical, i.e. lacking a central, predominant authority (Hill & Hupe, 2002; Marsh & Furlong, 2002). In this way, the governance perspective "draws attention to the diversity of actors, the diversity of their roles, the manifold relationships between them, and all kind of dynamic networks emerging from these relationships" (van Asselt & Renn, 2011: p. 434).

In the literature on risk governance, a distinction is often made between "simple" and "systemic" risks. Although this distinction may not be so straightforward to apply in practice, it contributes by highlighting some important aspects of the type of risks studied in this thesis. The former concept describes those risks for which there is a well-known cause-effect relationship, where the potential negative consequences are apparent, and the uncertainty and ambiguity is low (Renn et al., 2011; see also Löfstedt & van Asselt, 2008). Systemic risks, on the other hand, refer to risks that affect systems on which society depends, including for example transport systems and other infrastructures (OECD, 2003).

Systemic risks are trans-boundary in the sense that they are not restricted to single sectors or nations, and for these types of risks, interdependences and spill-over effects play an essential role (van Asselt & Renn, 2011). As further argued later in this chapter, managing systemic risks requires a holistic approach (Renn et al., 2011). The concept of systemic risk is frequently used in the literature on banking and finance. In broad terms, definitions of systemic risk in this field highlight the potential for breakdowns of entire systems, rather than breakdowns of individual components (Kaufman & Scott, 2003; see also Taylor, 2009, for other definitions). Although the use of the term systemic risk is far more restricted for studies of railways (where similar characteristics, according to Laperrouza, 2009, are described as risks giving rise to "cascading effects"), these types of risks are highly relevant for the railway system.

Systemic risks are characterised by a high degree of complexity (Renn et al., 2011). As will be described in more detail later in this chapter, complexity is often used to denote systems consisting of a large number of elements, and where these elements have non-linear connections (Érdi, 2008). In addition to complexity, two other features of systemic risks are often emphasised: uncertainty and ambiguity. The first of these concepts, i.e. uncertainty, is an essential part of the risk concept, since it makes no sense to talk about a risk if it is not associated with some uncertainty (Rosa, 1998). The second concept, i.e. ambiguity, may be seen as inherent in the concept of complexity, since all risks that are complex are likely to also be ambiguous or contested in some way (Löfstedt & van Asselt, 2008). However, the concepts of ambiguity and complexity are typically treated separately in the literature on risk governance.

The term ambiguity, as it is used in the field of risk governance, means that multiple values exist with regards to the evaluation of risk. Different actors respond to a certain risk in different ways as a result of their different interpretations and constructions of it. In other words, what counts as a risk is often different for different actors (IRGC, 2006a; Renn et al., 2011). As a result of the existence of multiple "frames", i.e. underlying structures of beliefs and perceptions (Schön & Rein, 1994; see also IRGC, 2006a; Jasanoff, 1998; Klinke & Renn, 2012; Lidskog & Sundqvist, 2012; Renn et al., 2011; Slovic, 2001; Tversky & Kahneman, 1981), considerable debate and disagreement may arise whether a specific risk should be seen as tolerable or not (van Asselt & Renn, 2011). If one viewpoint on risk is adopted, certain solutions may seem more advantageous. If another viewpoint is taken, other solutions may be preferred. In this way, whoever gets to control the definition of risk influences the choice of solution, and defining risk can thus be regarded as an exercise in power (Slovic, 2001).

By adopting a risk governance perspective, this thesis highlights the importance of paying significant attention to the ways in which various actors are framing risks. As will be described in the next section, the importance of framing is also emphasised in the area of systems safety research, particularly in research related to accident investigations and learning from accidents. This field constitutes the second pillar of the theoretical framework underpinning the thesis.

3.3 Systems Safety Research and Learning from Accidents

In the aftermath of accidents, the same event can be reconstructed in different ways, depending on the way the accident is framed (Catino, 2008). This means that our assumptions about why accidents occur are highly influential for determining what information will be collected, and hence, what will potentially be learned (Leveson, 2011). Assumptions about accident occurrence are often referred to as accident models, and in the area of systems safety research, these models have gradually developed from linear and componential, to systems-oriented approaches (Hollnagel, 2004; Hovden, Albrechtsen, & Herrera, 2010). This development reflects the insights gained from large-scale accidents in recent decades, showing that accidents in these types of systems typically emerge from the effects from decisions at various levels and at various points in time, rather than from individual failures or "human errors" in isolation (Rasmussen, 1997; Vaughan, 1996). As a result, investigation of the factors in close proximity, both spatially and temporally, of an accident scene does not give a full account of how and why the accident occurred. These factors are rather manifestations of demands, resources, and constraints produced by various organisational, administrative, and regulatory factors (Cook, Woods, & Miller, 1998; Rasmussen, 1997). For this reason, the scope of accident investigations should not be restricted to individual component failures, but rather, include relationships between factors at several levels of a socio-technical system (Leveson, 2011). These insights from systems safety research provided an important basis in this thesis, in particular in Papers III and IV.

In this thesis, a hierarchical representation of socio-technical systems has been used as a conceptual basis for illustrating that various levels of society are involved in risk management. This representation comprises a set of interrelated levels, and is based on the work by Rasmussen (1997). In later adjustments by Le Coze (2008), three main levels have been distinguished: the micro-level (work processes, equipment, and individual operators), the meso-level (collective and organisational level), and the macro-level (inter-organisational, societal level), see Table 1.

Table 1: A representation of socio-technical systems in three hierarchical levels

Macro-level	Societal level, including inter-organisational factors, regulations, authorities, inspectorates
Meso-level	Collective level, including organisational factors
Micro-level	Individual level, including human factors, work processes, equipment

The main purpose of accident investigations is to learn from an incident or accident in order to avoid similar events in the future. The term learning can be described as acquiring information, for example in the form of knowledge, understanding, techniques, and know-how (Argyris & Schön, 1996). It is common to talk about organisational learning (Argyris & Schön, 1996; Dodgson, 1993; Fiol & Lyles, 1985; Simon, 1991), which occurs either through the learning of the individual members of the organisation (since learning always takes place through individual humans), or when additional individuals (who contribute with knowledge not available before) join the organisation (Simon, 1991). To become organisational, it is essential that the knowledge acquired become embedded in the members' minds (e.g. in the form of norms and beliefs), as well as in the artefacts (e.g. procedures, rules, and documents) used in the organisation. Hence, learning can involve changes in states of knowledge as well as more visible changes in actions and structures (Fiol & Lyles, 1985). While these kinds of changes can be described as the product of learning, it is also possible to talk about the process of learning, i.e. the activity yielding such product (Argyris & Schön, 1996). This thesis is mainly focusing on the process of learning, which involves the activities and practices related to accident investigation as well as implementation of their ensuing recommendations.

While lessons can be learned in relation to all levels in Table 1, Hovden, Størseth, and Tinmannsvik (2011) have pointed out that it is also possible to talk about multi-level learning in another dimension. This dimension relates to different "loops" of learning, and has been described in similar ways by several authors, including Freitag and Hale (1997) and Argyris and Schön (1996). The lower levels, or single-loop learning, refer to changes in which the plan and strategy for achieving a certain goal is maintained, e.g. through deviance corrections. The higher levels of learning, or double-loop learning, refer to more fundamental changes, including a revision of the entire goal or strategy of the system.

Double-loop learning has proven difficult to achieve in practice (Boin, 't Hart, Stern, & Sundelius, 2005). The triggering event for learning to take place is typically some kind of surprise or discontinuity, i.e. a mismatch between the expected outcome of an action and the outcome actually achieved (Argyris & Schön, 1996; Nicolini & Meznar, 1995; Turner, 1976). In order to bridge this gap and "regain control" following an accident, it is usually easier to replace individual elements or blame a few people than to make fundamental changes of the entire system (or the views and assumption about its function). For this reason, scapegoating is sometimes a kneejerk reaction under the pressure to "do something". However, the search for someone to blame is counter-productive to learning, and builds on a simplified belief that safety can be achieved by getting rid of the "bad apples" in an otherwise safe system (Dekker, 2006).

Rather than seeing individual actors or components in isolation as the cause of failures, the complexity of modern systems calls for a need to study the relationships between various parts of the system (Dekker, 2011). In Perrow's view, failures should be seen as an expected by-product of the complexity characterising many of our socio-technical systems (Perrow, 1984). In this way, complexity plays an important role for research in the field of systems safety, as well as in the field of risk governance described above. Complexity theory has therefore been an important theoretical basis for this thesis, and will be further outlined in the next section.

3.4 Complexity Theory and Systems Perspective

The railway system is often described as a complex system (see e.g. Bårström & Granbom, 2012; Swedish Transport Administration, 2011). Although there is no clear definition of what is meant by a complex system, a number of commonly described characteristics can be identified. To begin with, a complex system is a system consisting of a large number of elements with many interactions between them (Axelrod & Cohen, 2000; Skyttner, 2005). These interactions are often non-linear and give rise to feedback loops, which means that some of the output from a process is passed back to its input. As a result, a small change in the cause can give rise to dramatic effects (Érdi, 2008), which is sometimes referred to as the butterfly effect (see e.g. Skyttner, 2005). In this way, causality in complex systems is circular, and there is no clear discrimination between causes and effects. Moreover, the behaviour of a complex system is often referred to as an "emergent" property, which means that the behaviour at the system level cannot be reduced to the properties of its constituent parts (Heylighen, Cilliers, & Gershenson, 2007).

It should be noted that systems consisting of a large number of elements do not automatically qualify as complex systems. Systems with large numbers of elements, but where the elements interact in simple and/or predictable ways (e.g. a watch) are better described as complicated systems (Axelrod & Cohen, 2000).

For a complex system consisting of a large number of elements and interactions, it is impossible to study the entire system at one time. For this reason, science has a long tradition of being reductionist (Checkland, 2006), i.e. decomposing a system in order to study its parts one by one and thereby drawing conclusions about their function. However, a system does not necessarily show the same properties when its parts are studied in separation as when the system is studied as a whole, since it is the relationships between the parts that give the system meaning (Godau, 1999; Senge, 2006). Therefore, by studying one element of a complex system at a time may result in overlooking some of the truly central characteristics of the system. This is the fundamental idea behind a systems perspective, i.e. to understand and manage a system's complexity by exploring it through holistic rather than reductionist thinking (Checkland, 2006).

A way of representing and analysing complex systems from a systems perspective is by using networks (Albert & Barabási, 2002). In a network, each element is represented by a node, and the relationships between elements are represented by links. By the use of a network approach, analyses of the properties of complex systems, including nonlinear interactions characterising such systems, can be undertaken. As a result of the increasing capacity of computer-based simulations, this approach has shown greater possibilities for analysing vulnerabilities stemming from interactions between diverse elements in large-scale systems (IRGC, 2009; Jenelius, 2007). This approach, which was adopted in Paper II, thus provides a valuable way of gaining insights into complex systems.

Modelling of critical infrastructure systems is a valuable approach for analysing their vulnerabilities to various types of threats (OECD, 2011). However, by definition, it is impossible to model a complex system in its entirety, since it is always necessary to reduce some of the system's complexity in order to create a model of it (Cilliers, 2001). This means that all potential failures to complex systems are never possible to anticipate. For this reason, it is essential that critical infrastructure systems also have a certain degree of resilience, i.e. an ability to continue operations, or recover to a stable state, after a major mishap (Boin & McConnell, 2007; McDaniels et al., 2008; Swedish Civil Contingencies Agency, 2011). The concept of resilience, which is further described in the next section, thus constitutes another important notion in this thesis.

3.5 Resilience and Vulnerability

Resilience is a concept used in numerous fields, including ecology, psychology, sociology, and engineering (Birkland & Waterman, 2009; Boin, Comfort, & Demchak, 2010; de Bruijne, Boin, & van Eeten, 2010; Swedish Civil Contingencies Agency, 2013). As mentioned above, the term resilience is used in this thesis to denote the ability of a system to continue operations, or to recover to a stable state, after a major disturbance (Leveson et al., 2006). For critical infrastructure systems, this view of resilience is frequently used for describing the ability of these systems to resist various types of failures or disturbances. For example, McDaniels et al. (2008) describe two key components of resilience of critical infrastructures: robustness and rapidity. With this view, the core of the concept lies in the ability of the system to withstand stress (robustness) and recover when such stresses occur (rapidity). These aspects are examples of the technical dimension of resilience. The concept of vulnerability, as used in this thesis, represents the antonym to this notion. Vulnerability can thus be defined as "the degree of loss or damage to a system when exposed to a strain of a given type and magnitude" (Johansson, Hassel, & Cedergren, 2011: p. 291), and a high degree of vulnerability corresponds to a low degree of robustness and/or rapidity.

In the field of systems safety research, which was described as one of the main theoretical pillars above, the term resilience generally holds a broader meaning. In this field, the concept includes the active decision-making and deployment of risk management strategies in dynamic settings, which reflects an organisational dimension of the concept (cf. MCEER, 2005). Since the railway system is a typical example of a socio-technical system, in which the social/organisational and technical dimensions are closely intertwined (Little, 2005), both the technical and the organisational dimensions of resilience are important to consider.

While essential aspects of the railway system's resilience comprise its robustness and rapidity (i.e. the technical dimension), the organisational dimension covers the ways these aspects are nurtured through the different institutional mechanisms involved in designing, operating and managing the system. In order to study how, and to what extent, the technical dimension of resilience is addressed in the railway system, the organisational dimension is thus of significant importance. This dimension of resilience has been extensively elaborated in the emerging field of resilience engineering, which has offered an important theoretical point of departure (see Hollnagel, Nemeth, & Dekker, 2008; Hollnagel, Pieri, & Rigaud, 2008; Hollnagel, Rigaud, & Besnard, 2011; Hollnagel, Woods, & Leveson, 2006; Hollnagel & Rigaud, 2006; Nemeth, Hollnagel, & Dekker, 2009).

According to Hollnagel (2008b), the novelty of resilience engineering lies more in the perspective it provides than in the methods and practical approaches adopted. In particular, this perspective includes the view that both failures and successes are the outcome of normal performance variability (Hollnagel, 2008b). This view of failure as the flip side of success motivates the study of processes under normal conditions and not only when things have gone wrong. Another aspect that sets resilience apart from related concepts used in the systems safety literature is the emphasis on the ability to adapt under varying conditions. In addition to being reliable, systems need to be able to recover from various threats and disturbances (Hollnagel & Woods, 2006). Resilience is thus about dynamic, not static, properties (Nemeth, 2009), and the ability to recover from failures does not necessarily imply a return to the original state (McDaniels et al., 2008; Pendall, Foster, & Cowell, 2010).

3.7 Summary

The different concepts and fields of research underpinning this thesis have a number of similarities. Resilience engineering has emerged as a sub-discipline in the broad field of systems safety research, and these two areas are thus closely connected. As described previously in this chapter, the fields of systems safety research and risk governance are linked by their emphasis on the importance of framing as well as the need to pay attention to the complexity characterising modern socio-technical systems.

In addition to these similarities, the different fields of research complement each other in several ways. Large focus in the field of resilience engineering is placed on the importance of individual teams and organisations being able to adapt under varying circumstances. However, it is important to recognise that the resilience of a system studied at one level is dependent on the levels above and below (McDonald, 2006; Woods, 2006a). The interactions between actors at various levels of a socio-technical system are therefore important to take into consideration, and for this reason, the perspective provided by the literature on risk governance supplements the ideas presented in the field of resilience engineering. Both of these fields provide important, and complementary, perspectives for managing risks in complex socio-technical systems. While resilience engineering highlights the need for a system to adapt in the face of various disturbances, the risk governance field emphasises the importance of paying attention to the diverse roles and perspectives held by the different players involved in managing risks in these types of systems. It can thus be concluded that these various fields of research have a number of common interfaces, and together, these somewhat overlapping areas provide the theoretical framework underlying this thesis.

4 Methods and Material

The objectives underlying this thesis were twofold: firstly, to identify challenges to risk governance in the Swedish railway system, and secondly, to provide increased knowledge and means to address these challenges. These different objectives called for different types of research approaches. The first objective gave rise to the studies presented in Papers I, III, and IV, which were mainly descriptive in nature, i.e. they aimed at gaining deeper understanding of specific phenomena. These studies were conducted as case studies, and the empirical data were collected by using content analysis and interviews. The second objective had a normative character, i.e. it was aimed at providing suggestions on how things ought to be. This objective was addressed in Papers II and V. Paper II involved method development, and the paper was based on computer simulations, workshops and document studies. In Paper V, a framework for analysing risk governance processes was proposed. Consequently, this paper also had a normative character. The usefulness of the suggested framework was demonstrated in two cases, and the empirical data in these cases were collected using content analysis and interviews (one of the cases was based on the data collected in Paper IV). The methods used in each of the appended papers are summarised in Table 2. In addition, this table summarises the empirical data collected in each paper.

Table 2: Summary of methods and empirical data for each paper

Paper	Research methods	Empirical data from interviews and workshops	Empirical data from document studies and content analyses
I	Interviews Document studies	16 respondents	Documentation from each project (1-8 reports from each of the 6 different projects)
II	Workshops Document studies Computer simulations	4 workshops involving 9 experts in total	Public as well as internal documents from the Swedish Transport Administration including e.g. system descriptions, maps, and yearly train time-tables
III	Content analysis Interviews	6 respondents (2 from each of the 3 accident investigation boards)	35 railway accident investigation reports (all reports from three countries issued during a two-year period, 2008-2009)
IV	Content analysis Interviews	14 respondents	Recommendations and feedback following 105 recommendations (all documentation available between 2004-2012)
V	Content analysis Interviews	14 respondents (same empirical data as used in Paper IV)	Same empirical data as used in Paper IV + 42 risk and vulnerability analyses conducted at the regional level in Sweden in 2008 and 2010 (21 reports from each year)

4.1 A Case Study Approach

Case studies are capable of dealing with the complex and dynamic characteristics of real world phenomena (Runeson & Höst, 2009). Unlike experiments and other fixed research designs, case studies are particularly useful when the researcher has limited control over events being investigated, and when the problem at hand is contemporary (Yin, 2003). These conditions are relevant for studies aimed at identifying challenges to risk governance in the Swedish railway system.

Examples of other flexible research designs often described as closely related to case studies include ethnographic studies and grounded theory studies (see e.g. Robson, 2002; Yin, 2003). However, unlike the grounded theory approach (which is aimed at generating theory from the data collected during the study, see e.g. Creswell, 2007), the studies presented in this thesis were conducted with pre-existing theoretical ideas and assumptions as points of departure (see Robson, 2002, for further discussion of a grounded theory approach). For this reason, grounded theory was not seen as a suitable research approach. Neither was an ethnographic approach (which according to Robson, 2002: p. 89, "seeks to capture, interpret and explain how a group, organization or community live, experience and make sense of their lives and their world") considered appropriate for the studies presented in this thesis. This was primarily because the risk governance perspective that was used as the main theoretical lens called for an analysis of the efforts taken by multiple stakeholders in the process of dealing with risks. Participant observation in all of the different organisations involved in this process would clearly be difficult to achieve in practice, particularly since ethnographic studies typically involve participation over extended periods of time where the researcher is immersed in the day-to-day lives of the organisation or people of interest (see e.g. Creswell, 2007).

The first case study conducted in this thesis (presented in Paper I) was exploratory in nature, and aimed at studying challenges to risk-related decision-making in multi-actor settings. The cases included six railway tunnel projects, and interviews were the key source of data collection, although a significant amount of documentation was also used as a basis for drawing conclusions from this study.

The studies presented in Papers III and IV were also conducted as case studies. As mentioned above, content analysis and interviews were the main sources of data collection used in both of these studies. While Paper III focused on identifying the type of factors attributed as causes in accident investigations, Paper IV focused on challenges related to implementation of the recommendations coming from these investigations.

Case studies are typically based on multiple data sources, and in this way, a case study represents an approach or strategy, rather than a method (Robson, 2002). The multi-method approach offered by a case study strategy thus allows data triangulation, i.e. the opportunity to collect information from multiple sources (Yin, 2003). The different sources used in the case studies included in this thesis (presented in Papers I, III, and IV) are described in more detail in subsequent sections.

4.2 Interviews

Risk governance is highly focused on the interactions between different stakeholders in the processes related to identification, assessment, communication, and decision-making over risks. In this thesis, the existence of multiple viewpoints on risk among the various players in this process was of particular interest. Since interviews are highly valuable for gaining understanding of the meaning that different people associate with a specific phenomenon in a specific context (Lantz, 1993), this approach to data collection has been extensively used in this thesis. It is important to recognise, though, that interviews are sensitive to the respondent bias, i.e. the possibility that the respondents perceive the researcher as a threat, and therefore withhold information, or try to answer in a way that they believe will satisfy the researcher (Robson, 2002). This potential threat to validity is further discussed in Chapter 6.3.5.

In order to allow for improvisation, inclusion of follow-up questions, and exploration of side-tracks, semi-structured interviews were conducted (see e.g. Runeson, Höst, Rainer, & Regnell, 2012). All interviews followed an interview guide that was distributed in advance in order to give the respondents opportunity to prepare themselves prior to the interview session. The interview sessions were typically initiated by explaining the purpose of the interview, which was also communicated before the interview. All interviews were transcribed and analysed based on common themes (see next section for a description of the approach to data analysis). In order to allow the respondents to correct misinterpretations, all respondents were given the opportunity to comment on a summary of the interview transcript, or on a draft of the final paper.

In Paper I, interviews with 16 respondents were conducted in order to gain understanding of the process as well as the outcome of decision-making at the design stage of railway tunnel projects. The respondents represented the Swedish Transport Administration (n=6), consultants (n=2), municipal building committees (n=5), and municipal rescue services (n=3). The questions asked in this case study related to the different stakeholders' experience of the decision-making process and selection of different types of safety equipment. Questions were also asked about the extent to which the railway system's ability to continue operation or quickly recover in the face of failures and disturbances was taken into consideration at the design stage of these projects.

A substantial part of the data collected as a basis for Paper II was conducted through the use of focus groups (which is a strategy for data collection closely related to interviews). In total, nine domain experts from the Swedish Transport Administration and the Swedish Railway Training Centre were involved in these focus groups. The primary objective with these focus groups was to create an understanding of the structure and functionality of the different sub-systems (as well as the interdependencies) of the railway infrastructure in order to be able to create a computer-based model of these systems.

In Papers III and IV, content analysis of relevant documents (see the next section) was conducted prior to the interviews. These analyses therefore guided the interviews, and gave rise to some of the questions that were addressed in the interview sessions. In Paper III, these questions related to the work processes related to accident investigations, the background and experience of the investigators, and the use of specific methods for accident investigation. Two investigators from the railway branch of the accident investigation boards in three countries were interviewed. The questions asked in Paper IV related to the respondents' experiences of challenges to implementation of recommendations from accident investigations. The respondents included in this study represented staff from the accident investigation board (n=3), the infrastructure provider (i.e. the Swedish Transport Administration, n=4), the safety authority (i.e. the Swedish Transport Agency, n=2), and railway operators (n=5).

4.3 Content Analysis

Papers III and IV were aimed at systematically analysing accident investigation reports and related official documents. Content analysis was used in order to conduct such analysis. In short, content analysis aims at reducing large portions of text into a small number of content categories (Weber, 1990). In this way, content analysis constitutes a structured approach for drawing inferences from text (Krippendorff, 2004).

In order to reduce the amount of data to a manageable size, it is usually necessary to apply some kind of sampling strategy, i.e. to make a selection of documents to analyse (Robson, 2002). In Paper III, where railway accident investigation reports from three national accident investigation boards were studied, a sample was selected to include the most recent reports in order to achieve high relevance of the results. Thus, all railway accident investigation reports issued during a two-year period (2008-2009) were selected for analysis (which constituted the most recently issued investigation reports at the time of data collection).

In Paper IV, the feedback from the safety authority to the accident investigation board with regards to the actions taken following safety recommendations were analysed. These documents were significantly shorter than the reports studied in Paper III. For this reason, the feedback following all recommendations available at the time of data collection was included in the content analysis (105 recommendations in total).

The content analyses were conducted by creating coding instructions, which provided guidance to the categorisation of the texts in question. The design of the categories created in the coding instructions naturally had a close connection to the research aim in the respective studies. In addition to providing support during the analysis, the coding instructions allowed for reliability testing. By conducting the analysis more than once for the same body of text, the stability of the results was tested. Moreover, by letting a previously uninformed person conduct the content analysis (by applying the coding instructions), the inter-subjectivity of the results was tested. This is further discussed in Chapter 6.3.2.

Content analysis can be used for many types of texts. In addition to the official documents analysed in Papers III and IV, content analysis was used to analyse the transcripts from the interviews conducted in Papers I, III, and IV. These transcripts were analysed by identifying specific key words or themes that were specified in advance. Common themes were grouped into categories, and based on this classification, inferences were drawn in order to address the research aims of each respective paper. In order to explicitly present the results from interviews, exact quotes were included in Papers I and IV.

4.4 Computer Simulations

As described in Chapter 3, computer simulation provides a valuable approach for systematic identification of vulnerabilities in large-scale and interdependent infrastructure systems. In Paper II, this approach was adopted in order to analyse vulnerabilities of the Swedish railway system. The first step of this approach was to translate models of the different sub-systems constituting the railway system into a computer code and to implement this code into a computer simulation program. Simulations were conducted by systematically removing elements from the models and evaluating the consequences. As further described in the next chapter, three different removal strategies were applied in order to analyse the system's vulnerability from different perspectives. The simulations conducted in Paper II were performed by using a single core AMD Athlon XP 2500+ processor. The computer code was implemented in Matlab.

4.5 Literature Review and Document Studies

In addition to the methods and techniques for data collection and analysis outlined in the previous sections, all studies were preceded by literature reviews in the relevant areas of research. Literature review is an indispensable part of research, and aims at familiarisation with various paradigms in the field of study. The literature review conducted as a basis for this thesis was based on literature searches in scientific databases. These databases included the database provided by Lund University called Lubsearch (and its predecessors Libhub and Elin@Lund) as well as ISI Web of Science, Scopus Direct and Google Scholar. The literature searches were initially conducted for specific keywords, and based on these keywords a large number of hits were generated. In addition to literature searches, cross-references were used to identify additional literature. These were skimmed and thereafter the most relevant sources were read more carefully (cf. Booth, Colomb, & Williams, 1995).

In addition to the literature searches conducted in scientific databases, significant amount of other background material was collected for the different papers. For example, this type of material included risk assessments and other type of documentation related to risk and safety management (collected in Paper I in the various railway tunnel projects) as well as different types of infrastructure system descriptions (collected as a basis for the computer simulations conducted in Paper II). In the same way as described above, these documents were skimmed, and the most relevant documents were read more carefully.

5 Research Contributions

This chapter firstly gives a short introduction to each of the five papers appended to the thesis. Secondly, the chapter presents the answers to the research questions, each of which is linked to a specific paper. Finally, the overall objectives of the thesis are addressed.

5.1 Introducing the Appended Papers

In this section, the scope and key findings of each of the five appended papers are presented. The next section provides a more complete account of the results from the papers.

Paper I

Cedergren, A. (2013). Designing resilient infrastructure systems: a case study of decision-making challenges in railway tunnel projects. *Journal of Risk Research, 16*(5), 563-582.

Paper I consists of a case study of risk-related decision-making at the design stage of railway tunnel projects in Sweden. This decision-making process is analysed from a theoretical perspective located at the intersection between the fields of risk governance and resilience engineering. In total, six different railway tunnel projects are included in the study, covering two thirds of the contemporary railway tunnel projects in Sweden at the time of data collection. Together, the six projects comprise a total of 28 railway tunnels. Two key players are involved in the studied decision-making processes: a project team (consisting of the Transport Administration and their appointed consultants) and a group of municipal actors (consisting of the municipal building committee and the rescue service). The results are based on semi-structured interviews with a total of 16 respondents representing these two key players, including representatives from the Transport Administration (n=6), consultants (n=2), municipal building committees (n=5) and rescue services (n=3).

The key findings from this paper show that decision-making at the design stage of the railway tunnel projects in many cases are characterised by significant controversy among the key stakeholders. Due to the diverse framings of risk held by the different stakeholders, deadlocks emerge in several of the projects, and power relations, negotiations and "precedents", i.e. decisions made in previous projects, shape the decision-making process. Due to the large emphasis on local aspects of each railway tunnel in the decision-making process, resilience of the railway system from a regional and national perspective receives limited attention.

Paper II

Johansson, J., Hassel, H., & Cedergren, A. (2011). Vulnerability analysis of interdependent critical infrastructures: case study of the Swedish railway system. *International Journal of Critical Infrastructures, 7*(4), 289-316.

In paper II, a method for vulnerability analysis of critical infrastructure systems is presented. This type of method is highly valuable for analysing an infrastructure system's ability to withstand and recover from failures, i.e. the system's resilience. Since the railway system is characterised by interdependencies between several infrastructure systems, the method is developed with particular consideration of the need to take these interdependencies into consideration. The method is applied to the southern part of the Swedish railway system. In order to create a model of this part of the railway system, empirical data is collected from document studies and four workshop sessions, including a total of nine domain experts.

The main results from this paper include the development of a computer-based method for vulnerability analysis that is specifically adapted to the railway system. The method includes the creation of both a structural and a functional model for each of the seven sub-systems comprising the railway system. The method also includes analysis of vulnerability from three complementary perspectives: global vulnerability analysis, critical component analysis, and geographical vulnerability analysis.

Author's contribution: The author played a major role in designing the study and collecting the data, and a medium role in writing the paper. The author played a minor role in writing the computer code and performing the simulations.

Paper III

Cedergren, A., & Petersen, K. (2011). Prerequisites for learning from accident investigations - A cross-country comparison of national accident investigation boards. *Safety Science, 49*(8-9), 1238-1245.

In paper III, all railway accident investigation reports issued by the national accident investigation boards in three Scandinavian countries during a two-year period (2008-2009) are studied. This corresponds to a total of 35 investigation reports. All reports are analysed with regards to the kind of factors they attribute as causing the accidents in question. Each attributed cause is categorised into one of three hierarchical levels. These levels include the micro-level (corresponding to actor activities, equipment, and physical processes), the meso-level (corresponding to factors related to management and other organisational aspects), and the macro-level (corresponding to factors at the societal level, such as inter-organisational aspects and regulatory bodies). In addition, interviews with two investigators from each of the three accident investigation boards are conducted.

The key findings from this paper are that the majority (between 68 and 78 per cent) of the attributed causes in accident investigation reports from the three Scandinavian countries can be found at the micro-level, while less attention is paid to factors at the meso- and macro-levels. The results from interviews indicate that investigators are inclined to focus on areas of their own expertise. Based on these findings, it is argued that the investigation boards should aim for a more diverse set of competences, and that further efforts should be devoted to exploiting the potential advantages associated with multi-modal accident investigation boards.

Author's contribution: The author played a major role in designing the study, writing the paper, and analysing the data, and a medium role in collecting the data.

Paper IV

Cedergren, A. (2013). Implementing recommendations from accident investigations: a case study of inter-organisational challenges. *Accident Analysis & Prevention, 53*, 133-141.

In paper IV, challenges to implementation of recommendations from accident investigations are studied. The theoretical framework underlying the study is based on the fields of risk governance, systems safety, and implementation research. The data providing the basis for the study consist of all recommendations following railway accidents issued by the Swedish accident investigation board at the time of analysis (105 recommendations in total). The first step of the study involves an analysis of the proportion of recommendations from these accident investigations that has not resulted in any action. In order to gain deeper insights into the reasons behind the difficulties related to implementation of these recommendations, an interview study involving a total of 14 respondents is conducted. These interviews include respondents from the accident investigation board (n=3), the safety authority (n=2), the infrastructure provider (n=4), and railway operators (n=5).

The main results from this paper show that almost one out of five (18 %) of the recommendations presented in official Swedish railway accident investigations have not resulted in any planned or implemented actions. Two main challenges to implementation are identified. Firstly, the results show that the different stakeholders involved in the implementation process hold diverse views regarding their own, and others', roles and mandates. Secondly, receivers of the recommendations experience an analytical gap between analysis of causes and recommendations on remedial actions.

Paper V

Cedergren, A., & Tehler, H. (Submitted paper). Studying risk governance using a design perspective. *Submitted to an international peer-reviewed journal.*

Paper V presents a conceptual framework for studying and analysing risk governance from a design perspective. A central element of the approach is to apply the so-called abstraction hierarchy in the context of risk governance. The use of the framework presented in this paper is exemplified by two separate cases; one relating to the implementation of recommendations from accident investigations (based on the empirical data collected in Paper IV), and one relating to risk and vulnerability analyses at three levels in Sweden (based on content analysis of 42 risk and vulnerability analyses).

The main results from this paper comprise the development of the framework for studying and analysing risk governance processes, which explicitly focuses on linking the micro-level activities related to managing risks with aspects at the macro-level. The framework allows analysis of risk governance processes from descriptive, evaluative, as well as normative approaches. One of the primary values of the framework is that it facilitates identification of a fragmentation of the risk governance process.

Author's contribution: The author played a major role in designing the study and writing the paper, and a medium role in collecting and analysing the data.

5.2 Addressing the Research Questions

5.2.1 Addressing Research Questions 1a and 1b

As described in Chapter 2, it is essential that critical infrastructures have a certain degree of resilience, i.e. that they are able to continue operations or quickly recover to a stable state after a major disturbance (McDaniels et al., 2008). Opportunities for providing resilience to the railway system exist already at the design stage of new railway tunnels, since this is when many essential characteristics of each tunnel are specified. At this stage, several stakeholders are involved in the decision-making process. In this type of multi-actor settings, the various actors often draw on different knowledge bases in order to influence the processes of risk analysis, risk management, and decision-making (Renn et al., 2011). Due to these divergent risk constructs, different meaningful, but equally legitimate, interpretations of risk assessment outcomes can be obtained (van Asselt & Renn, 2011). Considerable debate and controversy may therefore arise in multi-actor decision-making settings. For this reason, the following research questions were raised:

1a) Does the multi-organisational setting characterising railway tunnel projects in Sweden give rise to challenges to risk-related decision-making? If so, what are these challenges?

1b) To what extent is the railway system's resilience to failures addressed at the design stage of railway tunnel projects in Sweden?

These research questions were addressed in Paper I. As described in this paper, two key players are involved in the decision-making process at the design stage of railway tunnels: a project team (consisting of representatives from the Transport Administration and their appointed consultants) and a group of municipal actors (consisting of representatives from the local rescue service and the local building committee). Paper I showed that these two key players have different roles, they adhere to different sets of legislations, and they have diverse framings of risk. These differences gave rise to challenges to the decision-making process in the studied railway tunnel projects.

In particular, challenges to the decision-making process emerged with respect to the distance between evacuation exits. These exits are located at regular intervals inside each tunnel in order to provide means of evacuation. In addition, these evacuation exits are used as intervention points for the rescue service in the case of an emergency. The project team in each project suggested a design of safety measures, including a distance between evacuation exits, by using a risk-based approach. This design required an approved building permit from the local building committee before the tunnel could be taken into operation. However, the local rescue service, in its role as the building committee's expertise on safety-related issues, did not always agree upon the suggested amount of safety measures. More specifically, the rescue service generally did not share the risk-based approach, but rather saw the occurrence of an accident inside the tunnel in question as a starting point for decision-making (regardless the probability of such event). In this way, the two key players were framing risk in different ways. As a result of the more deterministic view on risk adopted by the municipal actors, they demanded additional safety measures as well as a shorter distance between evacuation exits in order to approve the building permit.

As a result of these disagreements, deadlocks emerged in the decision-making process in several projects, and both of the key players experienced that they were trapped in different types of double binds, i.e. decision-making situations requiring a choice between equally bad outcomes. The project team experienced that, on the one hand, they would face increased costs if they agreed upon the additional demands raised by the municipal actors. On the other hand, rejecting these demands would delay the project, and thus, also lead to increased costs. The municipal actors experienced another type of double bind: on the one hand, they felt that they would be blamed for delaying the project if they raised additional demands on safety measures. On the other hand, they feared that they would be blamed for having approved an insufficient level of safety in the case of an accident with severe consequences happening after the tunnel was taken in use.

In order to resolve these deadlocks, the project teams in some of the projects agreed upon a number of the demands raised by the rescue services. In this way, risk assessments were not the only, and in some cases, not the most important, basis for decision-making. Rather, decisions were largely based on negotiations between the different stakeholders, where power relations and "precedents", i.e. decisions made in previous projects, played important roles for shaping the outcome of the decision-making process.

Due to the need for an approved building permit, the municipal actors gained a prominent position in the decision-making process. Despite the important role each tunnel plays for a specific railway section (which in turn plays an important role in the larger railway network), the local perspective adopted by the municipal actors resulted in limited consideration being paid to the significance of the tunnel from a regional or national perspective. Specifically, the ability of the railway system as a whole to return to normal operation in case of a severe failure, i.e. the system's resilience from a regional or national viewpoint, received limited attention. This was particularly clear with regards to the choice of tunnel type in the studied projects.

Different tunnel types provide different opportunities to strengthen the railway system's overall resilience to failures and disturbances. Some respondents pointed out that a parallel single-line tunnel type offered a number of advantages, including increased ability for continued operation of the railway system in the event of failures or disturbances. According to these respondents, this solution would only have implied negligible additional costs. However, each tunnel project was run locally, and therefore, local aspects of each tunnel gained priority over the role that they play from a regional or national perspective, such as the way each tunnel influences the system's resilience. Consequently, due to the large emphasis on local matters in the decision-making process, a tunnel type providing a more restricted ability for the railway system as a whole to return to normal operation in the face of a serious failure was chosen in four out of six of the projects. In this way, Paper I showed that the local emphasis in the multi-actor decision-making process resulted in a restricted focus on resilience of the railway system from a regional or national perspective.

5.2.2 Addressing Research Question 2

In order to systematically identify vulnerabilities of the railway infrastructure, and thus, to provide opportunities to increase the system's resilience to failures, it is important to develop a method that is specifically designed for vulnerability analysis of the railway system. While similar methods have been suggested in related areas, this type of tool is rare in the railway system (Peterson & Church, 2008). This gave rise to the following research question:

2) How can a method be developed that enables systematic identification of vulnerabilities of the Swedish railway system, with particular consideration of the following aspects:

- *Interdependencies between sub-systems,*
- *Functional properties of sub-systems,*
- *Multiple simultaneous failures, and*
- *Multiple perspectives of vulnerability?*

In Paper II, a simulation-based method for vulnerability analysis of the railway system was developed. The suggested method included four main steps (see Figure 2). In the first step, the value basis underlying the analysis was explicitly addressed. In the second step, the interdependent systems were modelled and implemented in a computer simulation code. In the third step, simulations were performed from the three perspectives of vulnerability (further described below). Finally, in the fourth step, the results were presented and interpreted.

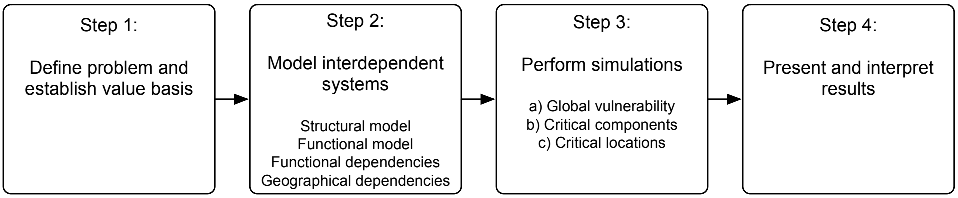

Figure 2: Overview of the main steps of the method for vulnerability analysis

The simulation model created in Step 2 included both a structural model and a functional model. While the structural model enabled representation of topological characteristics (the elements were represented as nodes and edges), the functional model allowed different elements to have different properties (in terms of, for example, electricity load and traffic load). These two types of models were created for each individual system, and dependencies between different systems were modelled by so-called dependency edges. In total, seven different systems were modelled, including: train operation, railway tracks, signal system, telecommunication system, traction power system, internal power system, and external power system. The train operation system was referred to as the focus system, since the consequences from various disturbances (measured as the number of trains unable to reach their destinations) was estimated for this system. The other six systems were referred to as supporting systems, since they together give rise to the functionality of train operation.

An important challenge facing the development of the method was the possibility of making a comprehensive analysis of the railway system's vulnerability. In order to address this challenge, three perspectives of vulnerability were included in the method (which were adopted in step 3). The three perspectives were referred to as global vulnerability analysis, critical component analysis, and geographical vulnerability analysis. The first of these perspectives, i.e. global vulnerability analysis, aimed at exposing one of the modelled sub-systems at a time to increasing number of removed elements (nodes or edges), and analysing the corresponding degradation in functionality for the system as a whole. The second perspective of vulnerability, i.e. critical component analysis, was aimed at identifying those elements that, if removed, gave rise to the largest consequences. This type of analysis was conducted by identifying the consequences related to removal of single elements, as well as removal of combinations of elements (two simultaneous failures). The final perspective of vulnerability, i.e. geographical vulnerability analysis, aimed at analysing the consequences arising by exposing specific geographical areas to strains (5 x 5 km large grid cells were used). This type of analysis thus focussed on the consequences of events affecting many elements in the same place, e.g. events caused by explosions, hurricanes or earthquakes.

The method was applied to the southern part of the Swedish railway system. By using the three perspectives of vulnerability analysis, it was concluded that complementary insights about the railway system's vulnerability were gained. For example, while geographical vulnerability analysis showed what areas are most vulnerable to large-scale consequences, critical component analysis showed which individual elements, or sets of elements, gave rise to the most serious consequences when they were subject to failures. From a comparison of these two perspectives of vulnerability, it was shown (not surprisingly) that the most critical elements were located in the areas with the highest traffic load. Moreover, the relative ranking of consequences arising from failures affecting each of the various sub-systems generally remained the same when the results from the global vulnerability analysis and the geographical vulnerability analysis were compared. This type of information, which is generated by applying the developed method, provides a valuable source of anticipation, and thus, an important input to efforts aiming at strengthening the railway system's resilience to various types of failures.

5.2.3 Addressing Research Question 3

The results from Paper I highlighted that the way risks are framed are important for the way they are managed. In the same way, framing is of significant importance in accident investigations, since the way an accident is framed in these investigations affects what potentially will be learned (cf. Catino, 2008; Hollnagel, 2008a; Hovden et al., 2010). The absence of definite guiding criteria for how far away (in space and time) from the immediate accident scene one should look in accident investigations (see Leveson, 2004; Rasmussen, 1990) calls for an analysis of what kind of factors gains most attention in these investigation reports. This gave rise to the following research question:

3) How much emphasis is placed on factors at different hierarchical levels (the micro, meso, and macro level, respectively) in official railway accident investigation reports, and what measures can be taken to change the focus of attention in such a way that it facilitates more effective learning from accidents?

In Paper III, all railway accident investigation reports from three Scandinavian accident investigation boards issued during a two-year period were analysed. A first step of this analysis involved the identification of attributed causes, i.e. factors that were described as contributory (but in themselves not sufficient) for the incident or accident in question. This identification of attributed causes was conducted by iteratively developing four categories of factors describing attributed causes. These categories formed the point of departure for the content analysis of the accident investigation reports, and included factors that were described as 1) deviations and deficiencies, 2) resource constraints and pressure, 3) ambiguities, and 4) variation in context and conditions.

Following the identification of attributed causes in the studied accident investigation reports, each attributed cause was categorised into one of three hierarchical levels. These levels included the micro-level (corresponding to actor activities, equipment, and physical processes), the meso-level (corresponding to management issues and other intra-organisational factors), and the macro-level (corresponding to factors at the societal level, such as regulatory bodies, inspectorates, and other inter-organisational aspects).

The results showed that the main focus of the accident investigation reports in all three countries was placed on the micro-level. More than two-thirds of all attributed causes were categorised into this level (between 68 and 78 per cent of the attributed causes in the reports from the three countries). This means that a basis for learning from accidents mainly exists for factors at this level. Less consideration was paid to the meso-level (between 19 and 27 per cent) and the macro-level (between 3 and 5 per cent).

Although important lessons can be learned about factors at the micro-level, the events and activities taking place at this level (such as the actions by individual operators, or the (mal)functioning of different types of components) are usually only the triggering event for an accident to happen. Rather than being the result of "human errors" or other micro-level events in isolation, a substantial body of contemporary systems safety research suggest that accidents in complex socio-technical systems typically stem from the way that constraints, incentives, and resources are produced by administrative, regulatory and organisational factors (see e.g. Cook et al., 1998; Dekker, 2006; Hollnagel, 2004; Leveson, 2011; Rasmussen & Svedung, 2000). This means that failures at the micro-level often merely represent symptoms of problems at higher levels of the system. Consequently, factors at this level only give a limited explanation of accident occurrence, and thus, a limited basis for learning. In this way, it is of major importance that higher-level aspects gain significant attention in accident investigations, since these aspects give rise to more effective learning, in the sense that more profound problems are addressed (and not only their symptoms).

Interviews with investigators from each of the three accident investigation boards indicated that the factors emphasised in investigation reports typically reflected the competences and experiences of the investigators, who mainly had technical or operational backgrounds. This means that investigators seemed to be inclined to focus on areas of their own expertise. The paper therefore emphasised the need for a greater diversity of competences among investigators that supplement purely technical or operational backgrounds, such as skills in psychology, human factors, organisational theory, law, and ergonomics. In order to facilitate a greater diversity of competences, despite limited resources, multi-modal accident investigation boards (i.e. the same investigation board responsible for investigation of accidents in multiple modes of transport and sectors) provide a number of potential benefits. The paper therefore underlined the importance of actively exploring the potential advantages of multi-modal accident investigation boards. For example, these advantages include the possibility of sharing facilities, administration, resources and training, as well as utilising cross-sector expertise and assisting each other in general investigation activities across different sectors.

5.2.4 Addressing Research Question 4

As described previously in this thesis, the accident investigations conducted by the national accident investigation board provide an important input to the governance of risk in the railway system. However, in order to accomplish risk-reducing actions, these recommendations should also be implemented. This gave rise to the following research question:

> *4) To what extent have recommendations from official railway accident investigations in Sweden resulted in implemented actions, and what challenges to implementation of these recommendations can be identified?*

Paper IV showed that almost one out of five (18 %) of the recommendations issued by the national accident investigation board following railway accidents in Sweden (until 2012) had not resulted in planned or implemented actions. In addition, the results showed that for 28 % of the recommendations, actions were only planned, but not yet initiated. This implies that the number of recommendations that are not followed by any actions may in fact be higher. All of the recommendations that had not resulted in implemented actions were divided into two groups, based on similar themes. The first group of recommendations included remedial actions described as not falling under the role or mandate of the receiver of the recommendation. The second group not resulting in implemented actions included remedial actions described as not relevant or necessary, since they, for example, already existed in current procedures or legislations.

Interviews with a number of key players involved in the implementation process provided deeper insights into the challenges of implementing the recommendations. From these interviews, two major challenges to implementation were identified. The first challenge related to the different stakeholders' diverse views on each other's roles, particularly regarding how closely tied the investigation board and the safety authority should be to the rest of the railway industry. This challenge can be described as a trade-off between being an insider and an outsider to the sector. This means that on the one hand, the investigation board and the safety authority need to have a certain degree of sector knowledge in order to understand the industry they are working with. On the other hand, if they are too immersed in the sector, there is a risk that they acquire a "tunnel vision", and are thus not able to identify problems or weaknesses in the sector.

The second challenge to implementation of recommendations was related to the scope of accident investigations and the ensuing recommendations. While considerable attention in these investigations was paid to the ways in which factors at the micro-level contributed to the accidents in question, many of the recommendations were directed at factors at the macro-level, without thoroughly describing the link between these levels. In this way, some respondents experienced an analytical gap between the analysis of causes and the recommendations on remedial actions, particularly since many of the suggested actions already existed in current procedures, work processes or legislations. This challenge to implementation can thus be described as a trade-off between factors at the micro-level and factors at the macro-level. While there is no doubt regarding the importance of identifying weaknesses at the micro-level of a socio-technical system (especially for the different operators that were involved in the accident in question), weaknesses at this level are often the results of pressures and constraints at levels above (as mentioned in the previous section). For this reason, investigation of processes at the macro-level provides understanding of more profound problems, and gives rise to counter-measures that are of cross-sector value.

The findings from Paper IV show that the multi-actor setting in which recommendations from accident investigations are dealt with give rise to challenges to implementation. It is therefore important not to restrict this type of studies to the activities of a single actor, but rather, to take into account the ways in which the interactions between various players influence the outcome of the implementation process. Unless this multi-actor perspective for studying the governance of risk is adopted, the outcome for each individual actor may seem satisfactory from the perspective of each player, even though the outcome on the level of the system as a whole may be sub-optimal.

5.2.5 Addressing Research Question 5

Based on the outcome from Paper IV, showing that challenges arise in the interactions between the various stakeholders involved in the risk governance process, the following research question was formulated:

> *5) How can a systematic approach for studying risk governance be developed that explicitly explores the link between the way risks are managed at the micro-level and aspects at the macro-level?*

In Paper V, a conceptual framework was developed to address the kind of challenges to the governance of risk identified in Paper IV. Particular focus was directed at relating the risk-related activities and products generated at the micro-level by individual analysts and decision-makers to aspects at the macro-level.

The framework presented in Paper V was influenced by design science, and for this reason, it is referred to as a design perspective to risk governance. Particular centrality was given to the so-called abstraction hierarchy, which can be used to describe complex socio-technical systems by using different levels of abstraction. While the number of levels in this means-ends representation varies in different uses of the abstraction hierarchy, the approach taken in Paper V was based on three levels. The first level constitutes the purpose of the system, which represents a description of the desired effects of a specific risk governance process. In the first example to illustrate the use of the approach to studying risk governance from a design perspective (which relates to the process of accident investigation and implementation of recommendations analysed in Paper IV) the purpose was to prevent future accidents and improve safety. In the second example (which relates to the undertaking of risk and vulnerability analysis in the public domain) the purpose was to compile a comprehensive overview of risks and vulnerabilities at various levels of Swedish society, in order to enable preparedness and mitigation activities.

The second level of the abstraction hierarchy is referred to as the function- level. At this level, the overall purpose of the risk governance process can be broken down into more specific activities that are necessary in order to fulfil the purpose. The generic activities described in various risk governance frameworks, such as risk identification, assessment, management, and communication, are examples of such risk governance functions. All of these activities can be defined by the output they produce. For example, the function risk identification is characterised by its output in terms of a set of events, risk sources, and their consequences. The second level of the abstraction hierarchy is particularly important for the conceptual framework, since this level represents the connection between activities and products generated at the micro-level of a socio-technical system, and aspects at the overall macro-level.

The third level of the abstraction hierarchy is referred to as the form-level. The different functions that are necessary to achieve the purpose of the risk governance process can be carried out in many different ways, and the form-level represents the actual physical documents, reports, etc. produced by individual members of the various organisations involved in the process of managing risks.

The design perspective to risk governance includes descriptive, evaluative, as well as normative approaches to studying and analysing risk governance processes. The descriptive approach aims at understanding and explaining a specific risk governance process, while the normative approach aims at constructing a new, or improving an existing, risk governance process. Finally, the evaluative approach aims at assessing whether a specific risk governance process achieves the established purpose(s).

As mentioned above, the use of the design perspective to studying risk governance presented in Paper V was exemplified by two separate cases. The value of the suggested approach was demonstrated in these two cases. From these applications of the framework, it can be concluded that, although further testing is desired, some promising results were achieved. In particular, it was concluded that the framework offers a systematic way of identifying fragmentation between different functions of the risk governance process. Since these various functions are undertaken by different stakeholders (including private as well as public bodies at different levels), this type of fragmentation of the risk governance process poses a severe problem. Even though each individual actor produces outcome that is in line with their role and mandate, sub-optimisations may arise at the system-level if these various risk governance functions are not fully aligned with each other. The value of taking this approach is therefore the possibility to identify disconnections, and as a result, to provide a basis for taking actions aimed at increased alignment of processes associated with the governance of risk at the various system levels.

5.2.6 Summary of Answers to the Research Questions

In Table 3, the research questions and the answers to these questions are summarised.

Table 3: Summary of research questions and answers to research questions

Paper	Research questions	Answers to research questions
I	1a) Does the multi-organisational setting characterising railway tunnel projects in Sweden give rise to challenges to risk-related decision-making? If so, what are these challenges? 1b) To what extent is the railway system's resilience to failures addressed at the design stage of railway tunnel projects in Sweden?	Due to diverse framings of risk, controversies and deadlocks arise in the decision-making process in several railway tunnel projects. Power relations and "precedents" shape the outcome of these decision-making processes, and both of the key players experience a double bind. Significant focus is directed at local aspects of each tunnel, rather than resilience of the railway system from a regional or national perspective.
II	2) How can a method be developed that enables systematic identification of vulnerabilities of the Swedish railway system, with particular consideration of the following aspects: – Interdependencies between sub-systems, – Functional properties of sub-systems, – Multiple simultaneous failures, and – Multiple perspectives of vulnerability?	A simulation-based method for vulnerability analysis of the railway system is developed, based on structural as well as functional models. Each of the seven sub-systems constituting the railway system is modelled, including dependencies between these systems. The method enables analysis of vulnerabilities from three perspectives: critical elements, global, and geographical analyses.

III	3) How much emphasis is placed on factors at different hierarchical levels (the micro, meso, and macro level, respectively) in official railway accident investigation reports, and what measures can be taken to change the focus of attention in such a way that it facilitates more effective learning from accidents?	Most focus in accident investigations is directed at aspects at the micro-level. As a result, the basis for lessons learned is primarily placed on factors at this level. The importance of a greater diversity of competences is emphasised, as well as more active exploration of the potential advantages associated with multi-modal accident investigation boards.
IV	4) To what extent have recommendations from official railway accident investigations in Sweden resulted in implemented actions, and what challenges to implementation of these recommendations can be identified?	Almost one out of five (18%) of the recommendations have not resulted in planned or implemented actions. The challenges facing the implementation of these recommendations stem from the fact that the different stakeholders hold diverse views on each other's roles, and that the receivers of the recommendations feel that the link between attributed causes of the accidents and recommendations on countermeasures is not thoroughly described.
V	5) How can a systematic approach for studying risk governance be developed that explicitly explores the link between the way risks are managed at the micro-level and aspects at the macro-level?	A framework for analysing risk governance processes based on an abstraction hierarchy is presented, which includes descriptive, evaluative and normative approaches. The framework facilitates identification of fragmented risk governance processes.

5.3 Addressing the Research Objectives

In this section, the overall research objectives are addressed. The first objective of this thesis was formulated as follows:

> *To identify challenges to risk governance in the Swedish railway system*

The research contributions outlined in the previous sections highlighted several challenges to risk governance in the Swedish railway system. First of all, the findings from the analysis of implementation of recommendations from accident investigations (Paper IV) showed that knowledge of each other's roles is critical for managing risks in multi-actor settings. The findings showed that limited awareness, or diverse views, of the roles and mandates of other players in the implementation process implied that expectations of one another were not always met. As a result, responsibility was unclear and essential risk-reducing actions in several cases were not taken. In the remaining chapters of the thesis, this challenge will be referred to as a problem of dispersed responsibility, denoting a failure of the various actors involved in the risk governance process to act cohesively.

A second challenge to risk governance identified in this thesis related to situations where one step of the risk governance process was not fully connected to subsequent steps. The results from the case studies of activities related to accident investigation and implementation (Papers III and IV) highlighted the importance of establishing a clear link between the analysis of factors contributing to an accident (i.e. the attributed causes) and the recommendations on measures to avoid similar events in the future. The results showed that unless this link is clearly described, receivers of the recommendations are unable to take risk-reducing actions. In the remaining chapters of the thesis, this challenge will be referred to as a problem related to a fragmentation of the risk governance process. This more general label denotes a difficulty to use the output from one risk governance activity as input to another risk governance activity.

A third challenge to risk governance identified in this thesis relates to situations where the various actors involved in decision-making over risks have different framings of the risk in question. As a result of these diverse framings, controversies and deadlocks may arise, which, in turn, can give rise to double binds, deadlocks, and decision-making based on negotiations and "precedents", which was the case at the design stage of several Swedish railway tunnel projects (Paper I). In addition to the challenges related to diverse framings of risk, the results from this thesis demonstrated that each framing of risk inevitably implies analytical sacrifices. This means that if one perspective is adopted, certain risks are identified, but if another view is taken, other risks come to mind. More specifically, the case study of decision-making in railway tunnel projects (Paper I) showed that significant focus was directed towards local aspects of each tunnel. As a result, the systemic features of the railway system, such as its resilience to failures from a regional or national perspective, received limited attention. Similarly, focus in accident investigation reports (studied in Paper III) was directed at factors at the micro-level. Consequently, a basis for learning from accidents mainly exists for factors at this level, while factors at the macro-level received less attention. These findings highlight that the way risks are framed is highly influential for the way they will be managed.

The second objective of the thesis was to address the challenges to risk governance, and the objective was formulated in the following way:

> *To provide increased knowledge and means to address challenges to risk governance in the Swedish railway system*

The way this objective has been addressed in the thesis is here summarised in two different themes. The first theme relates to the importance of approaching risks from a holistic perspective. The limited attention paid to the resilience of the railway system from a regional and national viewpoint (shown in Paper I) highlighted the importance of developing a method for analysing resilience and vulnerability from a holistic approach. Since the functionality of the railway system is dependent upon a number of co-existing and tightly coupled infrastructure systems, a failure to one system may propagate to other systems, and thus, result in significant failures. These types of cascading effects are difficult to overview and understand without a systematic and holistic approach to analysing vulnerabilities. In order to provide a tool that was able to address the resilience and vulnerability of the railway system as a whole, a method was therefore developed for vulnerability analysis specifically adapted to the railway system (which was presented in Paper II).

Particular attention in the development of the method for vulnerability analysis was devoted to taking interdependencies into account, namely by creating a structural and a functional model for each of the sub-systems comprising the railway system, and linking these models by dependency edges. Moreover, the method enabled analysis of vulnerabilities from three different perspectives, referred to as global vulnerability analysis, critical component analysis, and geographical vulnerability analysis. The type of output generated by this method provides valuable insights to efforts aiming at strengthening the railway system's resilience to various types of failures.

The importance of adopting a holistic perspective was also highlighted in relation to the process of accident investigations. Since the results from Paper III indicated that investigators focus on areas of their own expertise, the value of providing a diversity of competences among investigators, as well as the importance of actively exploring of the potential benefits associated with a multi-modal accident investigation board, was emphasised.

The second theme addressing the objective described above involves the need to cope with problems related to a fragmentation of the risk governance process. Paper IV demonstrated that challenges to risk governance arise when various risk-related activities that are undertaken by different players at different levels are not fully connected. As a result, individual actors may produce outcome that is consistent with their role and mandate, but still not optimal from the perspective of the overall system.

In order to address the challenge related to a fragmentation of the risk governance process (identified in Paper IV), a framework for studying and analysing risk governance processes was developed (presented in Paper V). This framework was influenced by design science, and particular focus was directed at establishing a link between the risk-related activities and products generated at the micro-level by individual analysts and decision-makers, and the risk-reducing outcomes arising at the macro-level. The framework facilitates identification of disconnections and misalignments between the purpose of a specific risk governance process and the form of the various types of documents produced in the various organisations involved in this process.

6 Discussion

This chapter starts by reflecting upon the theoretical framework and the research contributions. Later in the chapter, the quality of the research is discussed, and finally, suggestions on future research are presented.

6.1 Reflecting on the Choice of Theoretical Framework

As described in Chapter 3, several concepts and fields of research have provided important input to the theoretical framework underpinning this thesis. The field of systems safety research has been indispensable for gaining understanding of the way accidents occur, and how this view of accident occurrence has developed over time from a componential view to a perspective giving greater significance to the role of complexity, performance variability, normalisation of deviance and incremental drift towards safety margins (Dekker, 2011; Hollnagel, 2004; Perrow, 1984; Rasmussen & Svedung, 2000; Vaughan, 1996). This development of different accident models in systems safety research clearly marks the impact of different framings (i.e. different underlying structures of beliefs and perceptions) of a specific phenomenon, which has been a central theme in the thesis.

Despite the recognition in much of the systems safety literature that accidents do not arise as a result of individual component failures or "human errors" in isolation, but rather through the interplay between factors at multiple levels of a socio-technical system, research has traditionally focussed on each level separately (Rasmussen, 1997). Since the main interest of this thesis was to study the interactions between various actors at multiple levels, the field of risk governance was adopted as the primary theoretical lens. The concept of risk governance has been used in a broad sense. Rather than restricting the term to activities related to managing risks in a forward-looking perspective, is has also been used to involve processes related to accident investigation and implementation of recommendations. In this way, accident investigations are seen as intimately connected to risk analyses, and conceptually, an accident investigation is a type of risk analysis (Harms-Ringdahl, 2004).

By adopting a risk governance perspective, this thesis has given significant attention to the interactions between various stakeholders in their efforts to identify, assess and manage risk. As a result of adopting this perspective, it was possible to identify the challenges related to diverse framings of risks, dispersed responsibility, and fragmentation of the risk governance process (described in Chapter 5), which would have been difficult to do without a cross-organisational perspective.

Despite the centrality given to the term risk governance, it is important to point out that this field of research is in its early stages of development. The notion of risk governance was firstly introduced to the academic discourse at the turn of the millennium (van Asselt & Renn, 2011), and limited guidance has therefore been presented on how research in this area should be conducted. This was one of the reasons behind the development of the conceptual framework presented in Paper V, which is further discussed later in this chapter.

6.2 Reflecting on the Research Contributions

6.2.1 Exploring Diverse Framings of Risk

One of the main contributions of this thesis was to empirically demonstrate that the way risks are framed (i.e. the underlying structures of beliefs and perceptions of risks) is highly influential in shaping the outcome of the risk governance process (see also IRGC, 2006a; Klinke & Renn, 2012; Lidskog & Sundqvist, 2012; Renn et al., 2011). In this section, the importance of framing is discussed firstly in relation to accident investigations, and secondly, in relation to risk-related decision-making.

The outcome of accident investigations provides valuable knowledge in the effort of reducing risks and addressing weaknesses in the aftermath of accidents and incidents. In Sweden, like in most other European countries (see European Directive 2004/49/EC), it is the national accident investigation board that initiates an investigation of the causes leading to major railway accidents in order to avoid similar events in the future (in accordance with law 1990:712 and ordinance 1990:717). In addition, each organisation involved in a railway accident in Sweden normally conducts an internal investigation (see e.g. ordinance TSFS 2011:86 and instruction BVF 1906). While the investigations conducted by the operators or infrastructure providers generally are restricted to their own role and contribution to the accident, the national accident investigation board has the mandate to take the overall perspective, including the role played by the regulatory framework or other cross-sector aspects.

In this light, the results from Paper III (showing that the reports issued by the accident investigation board are mainly focussing on factors at the micro-level) indicate that the value added by these reports is limited, since these factors typically are covered by each organisation's internal investigation. This does not mean that investigation of factors at the micro-level cannot be valuable, for example for making continuous improvements of safety-critical equipment (see e.g. Leveson, 2002; Stoop, 2002). However, in complex socio-technical systems, factors at the micro-level (e.g. actions taken by individual operators, functionality of equipment, etc.) are typically manifestations of demands, resources, and constraints produced by various organisational, administrative, and regulatory conditions (Cook et al., 1998; Dekker, 2006; Hollnagel, 2004; Leveson, 2011; Rasmussen & Svedung, 2000). Thus, causes identified at the micro-level often merely represent symptoms of deeper problems in the system (Dekker, 2006; Kjellén, 2000; Rasmussen, 1990). For this reason, the scope of accident investigations should not be restricted to individual component failures, but should also include relationships between factors at higher levels of a socio-technical system (Dekker, 2011; Leveson, 2011).

The results from Paper III indicated that investigators focus on areas of their own expertise, which confirms the findings by Svensson, Lekberg, and Johansson (1999), showing that people with different backgrounds are framing accidents in different ways. These findings are in line with the more general line of reasoning by Cilliers (2005), who argues that any description of a complex system only takes a limited number of aspects into account, since different descriptions of the same system always decompose it in different ways. As a result, the knowledge drawn from any description is always contingent upon the viewpoint from which the description was made (Cilliers, 2005; see also Dekker, Cilliers, & Hofmeyr, 2011). In order to provide accident investigations that take multiple perspectives into account, it was therefore argued (in Paper III) that a larger variety of competences should be included in the national accident investigation board. These findings are in agreement with the arguments presented by Lundberg and colleagues (see Lundberg, Rollenhagen, & Hollnagel, 2009; Lundberg et al., 2010), who claim that sector-specific knowledge should be complemented by different types of specialist competences, such as skills in psychology and organisational theory (see also ESReDA, 2009; Rollenhagen, 2011).

While Paper III highlighted the role of framing for the outcome of accident investigations, the findings from Paper I showed that the way risks are framed is influential also for the way they are managed. More specifically, Paper I showed that diverse framings of risk gave rise to controversies and deadlocks in risk-related decision-making. In this way, the results from the railway tunnel projects studied in Paper I confirm the challenges involved in dealing with risks in settings involving multiple stakeholders who have different, but equally legitimate, standpoints, which has been raised by several authors (see e.g. Klinke & Renn, 2012; OECD, 2003; van Asselt & Renn, 2011).

Due to the diverse framings of risk among the different actors involved at the design stage of railway tunnel projects (studied in Paper I), the key players tried to influence the decision-making process in opposite directions. Thus, power relations between the various stakeholders were influential in shaping the outcome of this process. In this way, the results showed some important similarities to a study by Flyvbjerg (1998), who demonstrated the influential role of power relations between different stakeholders in the decision-making process at the design stage of another type of large-scale project. In more general terms, these findings confirm the view of Slovic (2001), who argues that defining risk represents an exercise in power.

Paper I also showed that both of the key players involved in the decision-making process felt that they were trapped in double binds, i.e. situations requiring a choice between equally bad outcomes (see e.g. Dekker, 2006; Hood, Rothstein, & Baldwin, 2001; Hood, 2002, for other examples of double binds in risk-related settings). These double binds gave rise to controversies and deadlocks, which in turn resulted in severe delays as well as significant socioeconomic consequences (in terms of substantially increased costs stemming from the delays occurring in several projects). In order to avoid the kind of deadlocks emerging in several of the studied railway tunnel projects, some respondents argued for a centralisation of the decision-making process in the sense that the need for a building permit should be removed. After the submission of Paper I, this change has *de facto* been implemented (see ordinance SFS 2011:338). On the one hand, this means that one of the primary causes to the deadlocks arising in the projects has been removed. On the other hand, however, the same stakeholders still hold central positions in the design stage of railway tunnel projects (according to the Planning and Building Act SFS 2010:900), although the formal basis for their participation in the decision-making process has somewhat changed. This makes studies of possible changes in power relations between the various stakeholders an interesting area for future research (see Chapter 6.4). However, irrespectively of whether the same type of problem will arise in railway tunnel projects in the future, similar situations are likely to arise in other decision-making settings. In order to avoid this scenario, more focus therefore needs to be placed on the challenges associated with risk-related decision-making settings where the different stakeholders have diverse framings of the risk in question.

Problems related to diverse framings of a specific problem are not unique to risk governance settings. Schön and Rein (1994) present examples of similar controversies from the field of policy analysis. In order to solve these problems, Schön and Rein (1994) suggest a process of re-framing, i.e. a process in which actors reflect on their own, as well as other actors', frames, which ideally leads to a situation where stalemates can be resolved (see also 't Hart & Kleiboer, 1995). Although a process of re-framing is recognised as a valuable approach, this solution is reactive rather than proactive, and can therefore not contribute to avoiding similar controversies in the future. For this reason, it is the author's view that greater efforts should be devoted to solving the controversies at a much earlier stage of the process, i.e. before deadlocks occur in the first place. In the case study presented in Paper I (and similar patterns were also found in Paper IV), it was clear that the problem-framing step was largely overlooked. In these cases, each stakeholder largely conducted an identification and evaluation of risk from their own perspective, without recognising that other players have a significant influence over the outcome of the risk governance process.

Based on these findings, this thesis points to the need for directing more attention towards the way risks are framed in the initial stages of the risk governance process. This view is in agreement with the suggestion outlined in the risk governance framework presented by IRGC (2006a), where the first phase involves a step referred to as problem framing. However, an important remark needs to be made with regard to the IRGC framework. Unlike the implicit assumption conveyed by this framework, it is important to emphasise that all stakeholders are not necessarily involved in all phases of a risk governance process. This means that problem framing (in the "pre-assessment phase" of the IRGC framework) is not necessarily conducted in a process involving all relevant actors, and there is generally no single actor with the overall responsibility for carrying out this step (or any other step) of the risk governance process. Unless other stakeholders' diverse framings of risk are recognised early in the risk governance process, there is a danger that problems in managing risk might arise in later stages. This kind of difficulty for each individual organisation to recognise their dependencies with other stakeholders is closely related to the challenges of dispersed responsibility and fragmentation of the risk governance process, which are discussed in the next section.

6.2.2 Addressing Dispersed Responsibility and Fragmentation of the Risk Governance Process

As described in the previous chapter, two challenges to risk governance were identified in the context of implementation of recommendations from accident investigations (presented in Paper IV). Firstly, the results showed that the various actors involved in this process had limited knowledge of each other's roles and mandates. In particular, the investigation board and the safety authority had different views on how closely tied the other player should be to the rest of the industry. This challenge entailed a trade-off between being insider versus outsider to the railway sector, and can be referred to as a problem related to dispersed responsibility, which has been described by IRGC (2009: p. 51) as:

> "[a] failure of the multiple departments or organisations responsible for a risk's management to act cohesively. This deficit can occur where complex interconnected systems require multi-actor and multi-level governance structures but no single entity has overall responsibility, or one entity has conflicting responsibilities. Overlapping, shared or unclear responsibilities, with poor communication and cooperation, can mean that important decisions will not be taken or will not be implemented"

The trade-off related to being insider versus outsider has been described in other contexts. For example, Vaughan (1996) warns against the danger of becoming "enculturated", i.e. that the investigators become so familiar with the system they are scrutinising that they cannot see it from an external and critical perspective (see also Woods, 2006b). At the same time, Dekker (2011) points out that an outsider role may give rise to a problem of lacking credibility. In the same way, Roed-Larsen and Stoop (2012), point out that total independence is neither practically possible, nor desirable, since this disconnects the investigation board from the operative environment (see also Dechy et al., 2012). In this way, the findings presented in this thesis confirm previous studies, and shows that the same issue is relevant also in the Swedish railway system.

The second challenge to risk governance that was identified in the context of implementation of recommendations from accident investigations occurred when the receiver of the recommendations from accident investigations felt that the link between analysis of factors causing the accident and the following recommendations was unclear. In several accident investigation reports, the factors described as causing the accidents were identified at the micro- or meso-levels, while recommendations were directed at the macro-level, without thoroughly describing the connection between these levels. This challenge entailed a trade-off between factors at the micro-level versus factors at the macro-level, and can be referred to as a problem of fragmentation of the risk governance process (denoting a situation where output from one step of the risk governance process is difficult to use as input to another step).

The problems related to identifying causes to accidents at the micro- or meso-levels, while directing recommendations at the macro-level have previously received limited attention in relation to implementation of recommendations from accident investigations. However, other authors have presented similar findings in related contexts. The difficulties associated with establishing a link between analysis and recommendations in accident investigations have been highlighted by Rollenhagen (2011) and Kjellén (2000) in more general terms, while the need to involve several levels of a socio-technical system in accident investigations has been emphasised by, for example, Leveson (2011) and Dekker (2011).

In the light of the deregulations within the Swedish railway system that have occurred in recent decades (see SOU 2008:92), it is not likely that the problems related to dispersed responsibility and fragmentation of the risk governance process will decrease in the future. While division of complex tasks among a number of actors may have positive effects in the sense that competition and specialisation contribute to increased efficiency, it may also lead to more focus being directed towards the partitioning of a task than on coordination of the various tasks to form a whole (Heath & Staudenmayer, 2000; Kramer, 2005). Division of the process of managing risks among a larger number of stakeholders may therefore imply that each actor is working in separate silos. When coordination and communication between these actors are lacking or deficient, this situation may lead to a "multi-organisational sub-optimisation" (Hill & Hupe, 2002), i.e. a process in which each organisation is pursuing its separate objectives but with outcomes that are not optimal overall (see also Ostrom, 1999; Woods & Branlat, 2011).

While the effects of multi-organisational sub-optimisation can be found at the macro-level, for example in terms of risk-reducing actions not being implemented, and thus, cross-sector learning not taking place, these effects often have their origin at the micro-level. It is at the micro-level (i.e. the level of individual operators or decision-makers) that negotiations over risks take place, risk-related documentation is produced, and decisions are made (Boholm, Corvellec, & Karlsson, 2012; Vaughan, 1996). This means that the link between different levels is highly important for gaining understanding of the ways that the management of risk at the lower levels of a socio-technical system gives rise to effects at the level of the system as a whole. In order to specifically address this micro-macro connection (cf. Vaughan, 1996), the approach to studying and analysing risk governance processes presented in Paper V was developed.

The framework outlined in Paper V was based on using the abstraction hierarchy (Naikar, Hopcroft, & Moylan, 2005; Rasmussen, 1985; Vicente, 1999). This means-ends hierarchy has been applied in other settings, including for example decision-support in emergency management (see Andersen, 2003) and in the military domain (see Naikar & Sanderson, 2001; see also Naikar et al., 2005, for additional examples). However, as a means to provide guidance to studying and analysing risk governance processes, the abstraction hierarchy has not previously been used.

The application of the abstraction hierarchy in a risk governance setting was based on two main reasons. The first reason stemmed from the findings in Paper IV outlined above, which highlighted the challenges related to dispersed responsibility and fragmentation of the risk governance process. These challenges illustrated the need for a closer connection between the different risk governance activities that are carried out by various players. The second reason was that this seems to be a neglected area in risk-related research. Focus in most research has been directed to one of the different levels separately (see Almklov & Antonsen, 2010; Rasmussen & Svedung, 2000; Rasmussen, 1997). In contrast, limited attention has been paid to efforts aimed at connecting the activities related to the management of risk at different levels of a socio-technical system in contexts involving multiple actors.

As mentioned in Chapter 3.2, the IRGC White paper on risk governance (IRGC, 2006a), including a risk governance framework, constitutes one of the most influential writings in the area of risk governance. The objective of this framework is described as providing guidance to comprehensive assessment and management strategies to deal with risks at the global level (IRGC, 2006a). However, the IRGC risk governance framework has been criticised on a number of points (see e.g. Löfstedt & van Asselt, 2008; Renn & Jäger, 2008; Rosa, 2008; Tjørhom, 2010). In particular, Boholm et al. (2012: p. 15) have pointed out that the IRGC framework represents an "idealistic" and "decontextualizing" approach to risk governance that is unable to capture the actual management of risk. These viewpoints are shared in this thesis. At the same time, contextualist studies fail to take the overall perspective into account, and thus, fail to draw conclusions regarding if and how the micro-level activities give rise to macro-level effects for the governance of risk.

The approach to analysing risk governance processes suggested in Paper V was illustrated in two separate cases. In the first of these cases, the empirical data collected as a basis for Paper IV (relating to the implementation of recommendations from accident investigations) were used to illustrate the value of the framework. The second case was based on empirical data on risk and vulnerability analysis at the local and regional levels in Sweden. These two cases showed that the approach can be used in completely different risk governance settings, and that it is useful as a means of highlighting disconnections between various risk governance functions. While the results from these examples are promising, it is necessary to test the framework in additional cases in order to evaluate whether it is applicable to other contexts, and whether revisions are necessary. This is therefore a topic for future research, which is further outlined in Chapter 6.4.

6.2.3 Approaching Risks and Vulnerabilities from a Holistic Perspective

Many scholars have emphasised the need for analysing risks and vulnerabilities facing critical infrastructures from a holistic perspective (Haimes, Kaplan, & Lambert, 2002; Johansson & Hassel, 2010; Little, 2005). However, a holistic approach seems difficult to sustain in practice (IRGC, 2009). The findings from this thesis clearly confirm this: In Paper I, local aspects of the railway system were adopted at the expense of the resilience of the railway system as a whole; in Paper III, focus in accident investigation reports was directed at factors at the micro-level, while limited attention was paid to factors at higher system levels, and finally; in Paper IV, each player focused on fulfilling their own tasks and responsibilities, while the coordination of activities between different players in order to achieve risk-reducing effects in the sector as a whole proved to be more difficult.

The findings from Paper I (showing that limited focus was paid to the fact that individual components may constitute significant vulnerabilities to the functioning of the railway system from a national perspective), paved the way for the development of the method for vulnerability analysis presented in this thesis. This type of method is vital as a basis for mitigation and preparedness activities related to critical infrastructure systems (Johansson, Jönsson, & Johansson, 2007). Due to the lack of methods capable of systematically identifying critical components in the railway system (Peterson & Church, 2008), the presented method fills an important research gap. Specific consideration was given to the role of interdependencies, since this represents a vital challenge to analysing vulnerabilities to critical infrastructure systems (Rinaldi et al., 2001). Due to these interdependencies, a failure affecting one (sub)system may propagate to other systems, resulting in significant consequences (Amin, 2001). In order to accurately characterise infrastructure systems, it is therefore essential that models and simulations take these interdependencies into account (Rinaldi, 2004). In the suggested method for vulnerability analysis, each of the seven sub-systems constituting the railway system was modelled, as well as dependencies between these systems.

In order to develop methods for comprehensive analysis of complex large-scale infrastructure systems, it is inevitable to make a number of trade-offs and analytical sacrifices. For example, in the current method, a trade-off was made between fidelity and abstraction. This trade-off was made in a way that aimed at including sufficient level of detail to actually represent the structure and functionality of the railway system, but still to remain practically possible to run. While it would have been possible to adopt more detailed models of the individual systems, this would have required longer simulation times, and would have restricted the possibility of making an analysis of multiple simultaneous failures in a reasonable time. On the other hand, less detailed models would have facilitated the inclusion of a model of the entire Swedish railway system, but at the same time, the lack of detail in this model would have affected the possibility of using the results as a basis for preparedness and mitigation activities.

By adopting multiple perspectives of vulnerability, it is possible to take the complex nature of infrastructure systems into account (Haimes, Lambert, Schooff, & Tulsiani, 1995; Murray et al., 2008). In the method developed in Paper II, three different perspectives of vulnerability analysis were included. While the inclusion of multiple perspectives provides complementary information, it is important to recognise that each perspective is associated with some drawbacks that possibly can be addressed in future work.

The first of the three perspectives involved critical component analysis, which provides valuable information of the most critical elements of the system. By systematically analysing the consequences of multiple failures, insights into the most adverse combinations of failures can be gained. This information is interesting since infrastructure systems often are designed according to the N-1 criterion (IRGC, 2006b), i.e. they are built to withstand a single failure (but not multiple failures).

However, due to the vast number of scenarios that arise when multiple failures are analysed, the application of the vulnerability analysis method presented in Paper II only included analysis of two simultaneous failures. With constantly increasing computer power, analysis of additional simultaneous failures should be possible in future simulations.

The second perspective of vulnerability, i.e. global vulnerability analysis, was conducted in order to study the consequences arising for the system as a whole when an increasing number of failures occur in one of the different sub-systems of the railway system. By using this perspective of vulnerability analysis, a comparison of the vulnerability of different sub-systems when they are exposed to the same number of failures can be made. However, it is important to note that the outcome from this type of analysis is dependent on which elements are affected by the failures, and on the order in which the different elements fail. For this reason, 1000 iterations were conducted for each simulation.

The final perspective of vulnerability, i.e. geographical vulnerability analysis, provides information of the vulnerability of a specific region, and therefore resembles the consequences arising in the face of, for example, flooding, landslides, or terrorist attacks. One of the shortcomings of geographical vulnerability analysis is that the outcome is highly dependent on the size and position of the cells, and for this reason, the method must be used with this limitation in mind.

The method for vulnerability analysis presented in Paper II builds upon network theory, which allows analysis of structural properties of an infrastructure system. One of the main contributions of the presented method is the extension of the network approach to include a functional model of each individual sub-system in order to take the diversity of functions into account. Even further developments of this approach are possible. For example, it would be possible to combine the presented method with approaches that take the potential propagation of the consequences from a specific disturbance outside the railway system into account, i.e. analysis of the societal impact from various failures or disturbances. For example, this can be achieved by combining the method for vulnerability analysis with the inoperability input-output model, which is based on approximation of economic data as an indication of interdependencies between different societal sectors (see e.g. Johansson, Svegrup, & Hassel, 2013). In addition to this potential scope for future research, further suggestions on how to improve the outcome from the suggested method for vulnerability analysis are presented in Chapter 6.4.

6.3 Reflecting on the Quality of Research

6.3.1 Validity

In contrast to quantitative research, the term validity is more difficult to operationalize in qualitative research (Robson, 2002). Yet, in order to undertake rigorous research, potential threats to valid results need to be carefully addressed. Many aspects of validity have been described in the literature (see e.g. Johnson, 1997; Maxwell, 1992). Interpretive validity refers to the accuracy in representing the thoughts and viewpoints that respondents attach to what is being studied. In Papers I, III, and IV, interpretive validity was addressed by recording the interviews and giving the respondents an opportunity to comment on a summary of the transcripts or on a draft of the paper in which the results were presented. Moreover, a final draft of Paper I was reviewed by an employee from the Swedish Transport Administration, who had good insights into the decision-making process at the design stage of Swedish railway tunnel projects (this person was not one of the respondents). In the same way, a final draft of Paper III was sent to all respondents, whereupon the authors of the paper were invited to one of the investigation boards to discuss the findings (and comments were received by email and by phone from the other two investigation boards, as well).

Another form of validity is referred to as theoretical validity, which relates to the importance of considering alternative understandings or explanations of the data (Robson, 2002). Johnson (1997) defines theoretical validity as the degree to which a theoretical explanation fits the data, and according to Maxwell (1992), theoretical validity is closely related to what some authors define as construct validity (see e.g. Yin, 2003). Johnson (1997) suggests several possible ways of addressing theoretical validity. One of these strategies relates to peer review of the research findings (Johnson, 1997). The studies presented in this thesis have been subject to two types of peer review. Firstly, the different studies have been scrutinised by colleagues in order to search for weaknesses. Secondly, the published papers have been subject to the conventional peer review by the various scientific journals where the papers were submitted. Another strategy to address theoretical validity involves theory triangulation, which relates to the use of multiple theories and perspectives to interpret and explain the collected data. Although theory triangulation in this sense was not conducted in the appended papers, two of the case studies (Papers I and IV) relied on multiple fields of research as the theoretical points of departure. In this way, insights from multiple research areas were considered at an early stage of these studies.

Other types of triangulation can be used in order to address various threats to validity (Robson, 2002). For example, data triangulation involves the use of multiple sources of evidence (Yin, 2003). Since risk governance by definition focuses on multi-actor management of risk, it has been emphasised in this thesis that the viewpoints of many actors need to be taken into account. In this way, data triangulation was a natural consequence of the risk governance perspective adopted as the primary theoretical lens. This was particularly the case in Papers I and IV, where the same types of questions were asked to multiple stakeholders involved in the process of managing risk, which allowed a comparison of the answers to identify the degree of convergence of the different stakeholders' accounts.

Moreover, in all of the three case studies presented in this thesis, data collection was not limited to interviews, but also included analysis of substantial amounts of documentation. In Paper I, risk assessments and other types of safety-related documentation from the different railway tunnel projects were studied, and in Papers III and IV, documents related to the process of accident investigation and implementation were analysed. Data triangulation was also used in Paper II, where a model of the southern part of the Swedish railway system was created by collecting data from documentation obtained from the Transport Administration, as well as from workshops involving several domain experts.

6.3.2 Reliability

In Papers III and IV, content analysis was conducted. Reliability of the results from the content analyses was checked in two ways. First of all, stability of the coding (i.e. whether the results were invariant over time) was checked by conducting the analysis of the material at least two times, resulting in good agreement in both papers.

Secondly, the inter-subjective agreement of the results (i.e. whether the same results were obtained when the material was analysed by different analysts, using the same instructions) was checked for both papers. For Paper IV, this was checked by asking a master's student (in risk management and systems safety) to use the coding instructions as a guide to conduct a content analysis on a randomly selected sample (60 %) of the material. The results from this test showed a 97 % agreement between the two analysts.

In Paper III, the inter-subjective agreement of the results from the content analysis was also checked by asking a master's student (also in this case a student in risk management and systems safety, but not the same person as in Paper IV) to use the coding instructions on a sample of the material (representing about one third of the studied reports). The results showed an 80 % overlap between the two analysts with regards to identification of causes, and a 96 % overlap with regards to categorisation. In this paper, inter-coder agreement was also calculated by using Krippendorff's α (see Krippendorff, 2004). This gave an α-value of 0.95, which represents good agreement.

6.3.3 Generalizability

Generalizability (sometimes denoted as external validity) refers to the consideration of whether the findings can be extended beyond the particular setting that was studied (Maxwell, 1992). While case studies have been criticised for allowing limited generalisation, Yin (2003) points out that it is important to separate statistical generalisation from analytical generalisation. While the former relates to the type of generalisation that is typical in, for example, survey research (by selecting a representative sample), the latter refers to the potential that a specific set of findings can provide theoretical insights into other situations or contexts (Robson, 2002; Yin, 2003).

Papers III and IV relate to the process of accident investigation and implementation of recommendations following railway accidents. These activities are regulated in the European Railway Safety Directive (European Directive, 2004/49/EC), which is common to all European member states. Although this directive is incorporated in national regulations in somewhat different ways in various countries, many of the findings are relevant to all countries of the European Union. In addition, similar requirements for accident investigations following major accidents can be found in other sectors as well as in other parts of the world. Due to these similarities, the findings from Papers III and IV are likely to be relevant also for accident investigation boards in other countries.

The method developed in Paper II was applied in a model specifically adapted to the Swedish railway system. However, significant similarities exist between the Swedish railway system and railway systems in other countries. Due to the increased harmonisation and interoperability of European railways (see European Directive, 2004/49/EC), these similarities are increasing. By using infrastructure data from other parts of Europe, it is thus possible to create models and apply the method to the railway systems in these countries, and most likely, to many other parts of the world. Moreover, in a wider sense, the approach to modelling interdependent infrastructure systems is not restricted to railways. Rather, the approach taken in Paper II, where a functional as well as a structural model was included, is applicable to modelling many other types of interdependent infrastructure systems.

The increasing harmonisation of standards and regulations across the European Union also relates to the construction of railway tunnels (in accordance with the technical specification for interoperability, TSI, 2008/163/EC). For this reason, many aspects related to risk and safety (studied in Paper I) are of interest to a number of countries. Moreover, the type of challenges to risk-related decision-making in settings characterised by multiple stakeholders with different roles and perspectives underlines the need to consider the role of diverse framings of risk at an early stage, which is a finding that is likely to have relevance in many similar contexts.

The conceptual framework suggested in Paper V was developed with the aim of being applicable to any risk governance process. Since this framework so far only has been tested in two cases, the limits to this generalizability are not well explored. Still, the generic nature of the three main concepts provides good opportunities for using the framework in many different risk governance contexts.

6.3.4 Researcher Bias

Researcher bias refers to the potential problem that the researcher finds out what he or she wants to find out, or that personal views and perspectives affect the way the research is conducted (Johnson, 1997). In order to address this threat to validity, it is important that the researcher reflects on his or her role and perspective.

The author of this thesis has no professional experience from the railway sector. While this may have implied a restricted understanding of traditions, culture, and work practices in this domain, it also enabled the author to take an outsider role in interview situations. Consequently, the author was not coloured by presumptions of how work practices "should" look in the railway system, but could be relatively open-minded, which possibly limited the researcher bias.

Another aspect of researcher bias relates to the choice of respondents as well as the sampling strategy of cases and documents (Robson, 2002). Although the first objective of this thesis was to identify challenges to risk governance in the Swedish railway system, this does not mean that the findings cover a complete picture of all potential challenges to the governance of risk in this domain. Naturally, practical constraints only allowed a limited number of case studies. This selection of cases potentially opens up for various threats to validity, and for this reason, the selection of cases and respondents needs to be reflected upon.

The selection of cases was made purposively with the aim of covering some of the most central governance settings in the Swedish railway system, which involved private as well as public stakeholders at multiple levels. The case study presented in Paper I was considered an interesting case from a risk governance perspective, since tunnels represent critical elements of the railway system, and since multiple stakeholders are involved in the risk-related decision-making process. In this case study, the majority of contemporary Swedish railway tunnel projects were included (six out of nine railway tunnel projects including tunnels longer than 1000m). Among the three railway tunnel projects that were not included in the study, one had a very specific character, since this railway tunnel was connected to the subway system. This placed specific demands on the design. The other two projects were at rather early stages of the project, and detailed risk assessments had not yet been conducted at the time of data collection.

Selection of respondents in the study presented in Paper I was associated with some difficulties. A large number of people have been involved in some part of the design stage of railway tunnel projects, all of whom came from varying professions and experiences. Since the Swedish Transport Administration is the authority responsible for building railway tunnels, respondents from this authority were firstly contacted. Two consultants, whose names were mentioned by several respondents, were also included in the interview study in order to benefit from their substantive experience in these types of projects. These consultants were appointed by the Swedish Transport

Administration, and consequently, their responses can be assumed to be influenced by this dependency. As described previously in this thesis, the decision-making process in several of the studied projects was characterised by controversy, and it was therefore highly important to include respondents with different roles and experiences. For this reason, respondents representing local rescue services and building committees were also contacted. These respondents were mainly identified by asking respondents from the Transport Administration for names of their counter-part in the decision-making process. Obviously, the selection of these persons may have been associated with some bias. On the other hand, the persons turned out to be the most experienced from these respective organisations. As mentioned previously, triangulation of the various respondents' different accounts and the various documents provided a basis for shedding light on the decision-making process from different perspectives.

In Paper IV, the accident investigation board and the safety authority hold crucial roles in the process of formulation and implementation of recommendations from accident investigations. Respondents from these organisations were therefore essential to include in the study. In addition, the Swedish Transport Administration is a central player in the railway system, due to its role and size, and inclusion of respondents from this authority was also seen as vital. The actual selection of respondents from these players was made by contacting each organisation with a description of the purpose of the study. The selection of the most relevant persons was thereafter made internally by each organisation. The key criterion for the selection of train operators was to include those operators who had been involved in an accident or incident that had been investigated by the investigation board. This criterion excluded some smaller train operators. For the same reason, the two largest train operators were especially interesting to include in the study, since they had been involved in several accidents (one freight train operator and one passenger train operator). The respondents from the infrastructure provider and the train operators held positions as safety managers or similar, since these persons were assumed to have most experience regarding the matters of interest to the study. No sampling of documents to include in the content analysis conducted in this paper was necessary, since all the feedback from recommendations issued by the investigation board (up to the time of data collection) was included in the study.

In Paper III, the investigation reports issued during a two-year period were selected. The most recent years were chosen, since these reports were assumed to most accurately reflect the current work practice of the three investigation boards. Interviews were carried out with two investigators from each of the three countries. The members of each of the investigation boards made the selection of respondents internally. However, since none of the investigation boards consisted of more than four railway accident investigators, the selection covered a large proportion of the staff, and the answers were therefore seen a highly representative of the investigators from each country.

6.3.5 Respondent Bias

In addition to the researcher bias discussed in the previous paragraphs, respondent bias constitutes a related problem to validity. Respondent bias refers to the possibility that the respondent perceives the researcher as a threat, and therefore withholds information, or that the respondent tries to answer in a way that he or she believes will satisfy the researcher (Robson, 2002).

As described in the previous section, the author of the thesis has no professional experience from the railway sector, which enabled the author to take an outsider role in interview situations. This may have limited the respondents' feeling that the researcher represented a threat. At the same time, other aspects may have had the opposite effect. In the interview sessions, it is the researcher who has the scientific competence as well as the right to set the agenda and select the questions to be asked. In this sense, the interview clearly invokes an asymmetrical power relation, which is important to acknowledge (Brinkmann, 2007). Moreover, many of the respondents had spent their entire professional lives in the railway sector, starting, for example, as train drivers and eventually climbed the career ladder to relatively high positions in their respective organisations. These respondents usually had limited contact with, and experience from, the academic environment, which therefore may have been experienced as threatening.

In order to address these issues, it was seen as important to establish trust at an early stage of each interview session. The author of this thesis also tried to use simple language, and avoid unnecessary use of scientific concepts in the interview sessions. Moreover, the interview questions were distributed in advance, and the purpose of the interviews was clearly described. Finally, as mentioned previously, each respondent was offered the opportunity to comment on a summary of the interview transcript or a draft of the paper where the results from the interviews were presented.

6.4 Future Research

The results presented in this thesis have given rise to additional questions and possible areas of study. Some suggestions on future research are therefore listed below.

- In recent years, the regulatory framework applicable to the construction of railway tunnels in Sweden (described in Paper I) has been changed. One of these changes involves removal of the need for a building permit for railway tunnels. A potential future study relates to investigating if and how decision-making in railway tunnel projects is affected by these alterations. In particular, such a study could focus on whether the power relation between the different stakeholders has changed, and accordingly, if any of the challenges identified in this thesis have been resolved.
- In the method for vulnerability analysis presented in Paper II, the restoration times following failures to the various sub-systems had an influential role for the outcome of the analysis. In an on-going project, more detailed analysis of these restoration times for various types of failures are collected through workshops with a wide range of actors involved in the restoration of the railway system following failures. By including these restoration times in the suggested method, increased accuracy of the outcome can be obtained.
- In Paper III, most attention was directed at the scope of accident investigation reports. More detailed comparison of work practices of different accident investigation boards would provide interesting insights into the way that learning from accidents can be improved. In particular, future studies could potentially focus on elaborating on different channels of knowledge-transfer that extend the current practice, by developing more dialogue-oriented approaches of sharing information and experiences.
- Paper IV emphasised various challenges to implementation of recommendations from accident investigations. Future research could take the opposite view, i.e. analysis of factors giving rise to successful implementation of recommendations.
- The framework for studying and analysing risk governance processes from a design perspective presented in Paper V has so far only been applied in two different cases. Although these two cases represent widely different risk governance settings, additional examples are necessary in order to evaluate the usefulness of the suggested framework. For example, it would be valuable to test cases where multiple, perhaps even conflicting, purposes of the risk governance process are present, or to use the framework as a basis for designing new risk governance processes.

7 Conclusions

The objectives of this thesis were to identify challenges to risk governance in the Swedish railway system, and to provide increased knowledge and means to address these challenges. The main contributions are summarised below:

- The results from this thesis reveal three important challenges to risk governance in the Swedish railway system. The first challenge involves a problem related to dispersed responsibility, which refers to situations that are likely to arise when the various actors involved in the governance of risk possess limited knowledge or different views on each other's roles and mandates. The second challenge involves a fragmentation of the risk governance process, which refers to a problem that is likely to arise when one step of the risk governance process is not fully connected to subsequent steps. Both of these problems exist in the process related to implementation of recommendations from official accident investigations in Sweden.
- The third challenge to risk governance in the Swedish railway system involves a problem of risk-related decision-making situations where the various stakeholders have diverse framings of the risk in question. These diverse framings of risk give rise to controversies and deadlocks at the design stage of several Swedish railway tunnel projects. In the face of these diverse framings, precedents, power relations and negotiations are likely to play important roles in shaping the outcome of the process related to governance of risk. Moreover, significant focus is directed towards local aspects of each tunnel. As a result, the systemic features of the railway system, such as its resilience from a regional or national perspective, receive only limited attention.
- In order to provide a basis for strengthening the railway system's resilience from a national perspective, a method for vulnerability analysis is developed, which explicitly addresses the interdependencies between different sub-systems. The method takes structural as well as functional aspects into account, and it is based on multiple perspectives of vulnerability. These perspectives include critical component analysis, global vulnerability analysis, and geographical vulnerability analysis.

- From an analysis of the way that railway accidents are framed in official accident investigation reports, it is concluded that the majority of attributed causes are identified at the micro-level (individual operators or equipment etc.). This means that a basis for learning from accidents mainly exists for factors at this level. However, problems at the micro-level of a socio-technical system are often manifestations of problems at higher system levels. Since the findings indicate that investigators are inclined to focus on areas of their own expertise, it is essential to highlight the value of providing a diversity of competences among investigators, as well as the value of exploring the potential benefits associated with multi-modal accident investigation boards.
- In order to enable identification of problems related to a fragmentation of the risk governance process, a framework is developed that explicitly links the way risks are handled at the micro-level to aspects at the macro-level of a risk governance process. The framework is influenced by design science, and allows descriptive, evaluative, as well as normative approaches to studying risk governance processes.
- Finally, the thesis demonstrates that the risk-related activities conducted by an individual actor may be consistent with this actor's particular goals and mandates, but sub-optimal from a cross-sector point of view. These findings would be difficult to identify if each stakeholder was studied in isolation, and in this way, the thesis contributes by highlighting the value of adopting a multi-actor perspective for studying the way risks are managed.

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