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Abstract: In order to minimise the impact on society in the case of severe disturbances affecting infrastructure systems it is essential that these systems are resilient to failures, i.e. that they are able continue operations or quickly recover a stable state after a major mishap. Numerous opportunities for taking measures to increase resilience of infrastructures exist already in the design phase of new elements in these systems. This paper therefore investigates to what extent resilience of the railway system is considered at the design stage of new railway tunnels in Sweden. The case study builds upon interviews with key stakeholders involved in the decision-making process regarding safety measures in six railway tunnel projects, comprising a total of 28 tunnels (representing the majority of contemporary railway tunnel projects in Sweden). The theoretical perspective is based upon insights from the fields of resilience engineering and risk governance. The results revealed that power relations between the different stakeholders largely influenced the decision-making process in the studied railway tunnel projects. Diverse roles and perspectives among these actors led to disagreements in the majority of the projects. As a result, both of the key stakeholders experienced that they were trapped in different kinds of double binds, i.e. situations requiring a choice between equally bad outcomes. These double binds, and the significant influence from local actors on decision-making, resulted in a restricted consideration of the system's resilience on the regional and national levels. These findings underline the important relationship between decision-making at the local level in each railway tunnel project and the impact from these decisions on the system's resilience at the global level. The paper therefore contributes to increased understanding of the way that micro-level decisions affect macro-level characteristics of complex socio-technical systems.

Keywords: resilience; risk governance; double bind; infrastructure; railways

1. Introduction

Our society is largely dependent upon the reliable function of a number of infrastructure systems, including for example transport systems, electrical power distribution and water supply (Almklov and Antonsen 2010; de Bruijne and van Eeten 2007; Rinaldi, Peerenboom and Kelly 2001). Failures affecting these infrastructures have a potential for severe consequences both in terms of human and economic loss. The importance of this kind of systems for providing essential services supporting a nation's economy and social well-being is reflected in the terms Critical Infrastructures (CIs) or 'lifeline systems' (McDaniels et al. 2007; Little 2004). As a result of their increasing complexity, they have become more interdependent (Amin 2001). This means that a failure affecting one system have the potential to cascade into other systems, resulting in significant damage (Little 2002; Rinaldi, Peerenboom and Kelly 2001; Ansell, Boin and Keller 2010). It is therefore essential that these systems are resilient to failures in the sense that they are able to absorb shock while maintaining function (McDaniels et al. 2008). This is highlighted in a recent national Swedish strategy for protection of essential societal functions. The overall goal of this strategy is declared as providing society as a whole, including its critical infrastructures, with an increased degree of resilience (Swedish Civil Contingencies Agency 2011). However, the realisation of this goal in practice is unclear and needs to be further studied.

Several authors have proposed ways to analyse infrastructure systems in the effort to provide increased resilience and reduce their vulnerability (see e.g. Johansson, Hassel and Cedergren

2011). Whereas these activities have mainly focused on existing infrastructures, numerous opportunities for taking measures to increase resilience exist already at the design stage of new elements in these systems. In the design phase of infrastructures decisions regarding many of the characteristics that shape the system's ability to withstand future failures are made. By studying decision-making at this stage, valuable insights can therefore be gained of the way that risks and vulnerabilities to the system's operation are managed. In this case study such decision-making process at the design stage of railway tunnel projects in Sweden is analysed. The objective of the paper is to study to what extent resilience of the railway system is considered in the multi-actor decision-making setting characterising railway tunnel projects. The objective is also to identify challenges related to the provision of resilience to this kind of interdependent socio-technical system (see also Cedergren 2011 for a brief outline of some preliminary findings).

The paper is structured as follows. Firstly the paper describes the theoretical framework for analysing the provision of resilience to infrastructures in a multi-actor decision-making setting. This theoretical point of departure draws upon insights from the fields of resilience engineering and risk governance. The next section describes the studied railway tunnel projects, and the approach for conducting the study. In Section 4 the results of the studied cases are presented, and the challenges of providing resilience to this type of interdependent infrastructure projects are addressed. Thereafter follows a discussion of the findings, and finally some conclusions are drawn.

2. Theoretical framework

In order to study challenges related to the provision of resilience to the railway system the concept of resilience first needs to be elaborated. The term resilience is often described as the ability to bounce back, or return to normal functioning despite continuous stresses. In this general sense, resilience is a concept that is described in a number of different fields, such as ecology, psychology and engineering (de Bruijne, Boin and van Eten 2010; Birkland and Waterman 2009). The concept has gained significant popularity in recent years, and as pointed out by Boin and colleagues 'It appears that everything (organizations, cities, nations) and everybody (from schoolteachers to the U.S. president) can and should be resilient' (Boin, Comfort and Demchak 2010, 1).

2.1. Resilience engineering

In safety science, resilience typically refers to the ability of a system to 'continue operations or recover a stable state after a major mishap or event' (Leveson et al. 2006, 95). This is the meaning of the concept adopted in this paper. In recent years similar definitions of the term resilience have been proposed in the emerging field of resilience engineering (see Hollnagel and Rigaud 2006; Hollnagel, Woods and Leveson 2006; Hollnagel, Nemeth and Dekker 2008; Hollnagel, Pieri and Rigaud 2008; Nemeth, Hollnagel and Dekker 2009; Hollnagel, Paries, Woods and Wreathall 2011; Hollnagel, Rigaud and Besnard 2011). Central to the ideas advanced in the resilience engineering literature is the ability of a system to adapt under varying circumstances (Hollnagel 2011b). According to Woods (2003), resilience engineering is built upon insights derived from research on failures in complex socio-technical systems across various sectors, particularly the organisational contributors to risk. Based on these different research findings, a number of generic patterns of vulnerabilities in decision-making have been identified (Woods 2003). The basis for these insights have been synthesised from various research contributions, including for example findings from studies of High Reliability Organisations (see Weick, Sutcliffe and Obstfeld 1999).

These patterns have been described by Woods (2003) as being important challenges for managing a system's resilience. In this paper they have therefore been used to provide the point of departure for the analysis of decision-making in railway tunnel projects. These challenges include:

(1) Failures to revise assessments as new evidence accumulates.
(2) Breakdowns at the boundaries of organizational units that impedes communication and coordination.
(3) Taking past success as a reason for confidence instead of investing in anticipating the changing potential for failure.
(4) Fragmented problem solving process that clouds the big picture.

The extent of consideration that is given to resilience of the railway system has been analysed by studying the way these challenges are managed in railway tunnel projects. The first of these challenges involves the inability to revise assessments in the face of new evidence. As pointed out by Lidskog, Uggla and Soneryd (2011), the framing of a specific problem exerts significant influence on what knowledge that is seen as relevant (see also Slovic 2001). Interaction between people with diverse perspectives is therefore essential in order to look at previous facts in a new way (Dekker 2005). The fresh perspectives added by different framings provide an organisation with a broader set of assumptions that makes it more sensitive to a greater variety of different inputs. However, Weick and colleagues (1999) remark that this ideal may be difficult to achieve in practice due to conflicts and disagreements when actions need to be taken. Emergence of such conflicts typically makes different views polarised and leads to a failure to revise assessments.

The second challenge, breakdowns at the boundaries of organisational units, refers to a lack of mechanisms for effective interplay across groups and organisations. Kramer (2005) provides several examples of factors leading to such cross-boundary breakdowns in his analysis of the failure to cooperate effectively across various U.S. agencies prior to the 9/11 attacks. As a basis for his analysis he refers to the 'tragedy of the commons'. This parable refers to the conditions under which locally rational courses of action inevitably lead to collective breakdown (see also Ostrom 1999). Behind this challenge lies an inability to coordinate different groups at various levels when they are facing conflicting goals. Woods and Branlat (2011) remark that mis-coordinated groups sometimes work hard to achieve local goals. However, this way of locally pursuing a set of specific goals may sometimes overshadow goals at the system level.

The third challenge, taking past success as a reason for confidence, describes how the present course of action adopted by an organisation is justified by its successful history. For example, the absence of failure is seen as evidence that existing safety measures are effective, or even that hazards are not present (Dekker 2005). As pointed out by Starbuck and Milliken (1988, 329) 'success breeds confidence and fantasy' and makes organisations more convinced of their own abilities, skills and procedures. This challenge clearly contrasts one of the distinctive qualities of High Reliability Organisations, which are characterised by a chronic worry that analytic error is embedded in its ongoing activities (Weick, Sutcliffe and Obstfeld 1999). These organisations therefore possess a continuous expectation of future failures (Rochlin 1999), which keeps them watchful for the potentially misleading inferences drawn from past success.

The fourth challenge described by Woods (2003) is fragmented problem solving. This challenge emphasises the danger of focusing on specific details at the expense of recognising the bigger picture. The way that a complex system is described depends on the manner in which the boundaries of what constitutes the system and what constitutes its environment are defined (Cilliers

2001). Consequently, if the chosen system boundaries are restricted to a few aspects, the influence these aspects have on the larger functioning of the system is excluded. As a result the outcome may be unsatisfactory, sub-optimal, or even counter-productive. This type of fragmentation is a highly relevant topic for critical infrastructures. Whereas these systems are becoming physically more tightly coupled their management is characterised by an increasing institutional fragmentation (de Bruijne and van Eeten 2007). This means that their operation and supervision is divided between a larger set of different organisations.

A further remark concerning the four[1] challenges adopted for analysing decision-making in this paper should be made. A large part of the contributions to the field resilience engineering are focusing upon the strategies and abilities to adapt and survive within individual teams and organisations. This is reflected in many definitions of the term resilience that can be found among the contributions to the resilience engineering field (see e.g. Sundström and Hollnagel 2006). Likewise, most suggestions on indicators for the provision of resilience focus upon individual organisations. Due to the immaturity of the field the theoretical development and empirical validation of such indicators are yet limited. Among the few examples presented to date the suggestions on indicators from Hollnagel (2011a) and Macchi et al. (2011) can be mentioned. However, as pointed out by Woods (2006, 23) 'the resilience of a system defined at one scale depends on influences from scales above and below'. This means that studies of resilience should not be restricted to the organisational level. Rather, analyses that include the interactions between multiple levels of a socio-technical system may also provide interesting insights to studies of risk-related decision-making. One of the essential challenges for resilience engineering is therefore to produce the research that will identify the specific features of a socio-technical system that do in fact give resilience (McDonald 2006).

2.2. Risk governance

Whereas limited consideration has been devoted to multi-level decision-making in the field of resilience engineering, this type of setting has gained significant attention in the field of risk governance. In this field a number of factors described as 'failures' to the risk management process have been identified. Some of these 'risk governance deficits' (IRGC 2009) have significant similarities to the challenges of managing a system's resilience described above. This demonstrates that the findings identified in the field of resilience engineering are relevant also in a multi-organisational setting. Particularly, the following four risk governance deficits (IRGC 2009) maps remarkably well onto the challenges described above:

- Missing, ignoring or exaggerating early signals of risk, for example by failing to be open-minded as to the interpretation of low-level or subtle signals of risk (comparable to 'failure to revise assessments as new evidence accumulates')

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[1] A fifth challenge presented by Woods (2003) includes 'drift toward failure'. However, even though drift toward failure possibly has a great impact on a system's resilience, a longitudinal study of a system's operational phase would be required for examining drift toward failure. Therefore, this factor has not been considered in the analysis.

- A failure to resolve conflicts where different pathways to resolution may be required in consideration of the nature of the conflict and of different stakeholder interests and values (comparable to 'breakdowns at the boundaries of organisational units')
- Failure to re-assess in a timely manner fast and/or fundamental changes occurring in risk systems, for example by continuing to behave as if risks follow known routines (comparable to 'taking past success as a reason for confidence instead of investing in anticipating the changing potential for failure')
- A failure to understand how the components of a complex system interact or how the system behaves as a whole, thus a failure to assess the multiple dimensions of a risk and its potential consequences (comparable to 'fragmented problem solving process that clouds the big picture')

These similarities show that resilience engineering and risk governance share a number of common ideas related to risk-reducing strategies, but they focus on somewhat different aspects. Resilience engineering, on the one hand, emphasises the need for a system to adjust its functioning in the face of varying risks (Hollnagel 2011b). Risk governance, on the other hand, highlights the difficulties in reaching binding decisions in a multi-level, multi-organisational setting in which none of the actors possess superior authority (van Asselt and Renn 2011). The topic of interest for this study lies at the intersection between these fields. As a basis for the theoretical framework of this paper ideas from the field resilience engineering have therefore been complemented by insights from the field of risk governance.

The notion risk governance refers to the various ways in which a multitude of actors (individuals, institutions, public and private bodies) 'deal with risks surrounded by uncertainty, complexity and/or ambiguity' (Renn, Klinke and van Asselt 2011, 233). Particular emphasis is provided to risk-related decision-making situations where 'the nature of the risk requires the collaboration of, and co-ordination between, a range of different stakeholders' (IRGC 2005, 22). As a consequence, the concept includes the totality of various rules and processes and the diverse number of actors involved in collecting, analysing, and communicating risk-related information (Renn, Klinke and van Asselt 2011; van Asselt and Renn 2011; IRGC 2005). This means that the scope of risk governance is fundamentally multi-organisational. In situations involving actors at different levels of society (local, regional, national), the term multi-level governance is used (Renn, Klinke and van Asselt 2011). These diverse actors are typically characterised by different perceptions and evaluations, and they draw on different knowledge and evidence claims in order to influence risk-related decision-making (Renn, Klinke and van Asselt 2011). These differences in legitimate viewpoints from time to time lead to various types of controversy in decision-making, including for example deadlocks and legitimacy problems (van Asselt and Renn 2011). The notion ambiguity is used in the risk governance field to refer to such controversy stemming from the existence of multiple values (Renn, Klinke and van Asselt 2011).

In order to provide guidance for improved risk governance the International Risk Governance Council (IRGC) has developed a framework for 'the development of comprehensive assessment and management strategies to cope with risks' (IRGC 2005, 11). However, this model has received criticism on several points. For example, Boholm Corvellec and Karlsson (2012, 15) raise an important aspect by declaring that they 'challenge the IRGC's decontextualizing approach to risk governance, an approach that stays at a methodological and theoretical distance from the micro contexts in which risk understanding gets born and risk decisions are made'. This point is shared in this paper, where significant focus is devoted to decision-making at the micro-level in each studied project. Particularly, the paper aims at gaining deep insights and understanding of the local rationality of each stakeholder. Therefore, the approach to studying challenges associated with risk-related decision-making is built upon an exploratory case study with interviews as the primary method for data collection. This approach will be further described in the next section.

3. Method and material

This exploratory case study builds upon data collected from semi-structured interviews with a total of 16 persons involved in the design stage of six railway tunnel projects in Sweden (out of a total of nine new railway tunnel projects comprising tunnels more than 1000 m under design or construction in Sweden at the time of data collection). The six railway tunnel projects together encompass 28 tunnels. These tunnel projects include: the City tunnel project, the Botniabanan project, the Ådalsbanan project, the Hallandsås project, the Nygård tunnel project, and the Kiruna project. An overview of some key characteristics of the tunnels is provided in Table 1.

Table 1. Description of tunnel projects

Project	Number of tunnels	Tunnel length	Traffic volume (trains per day)	Tunnel type	Location
The Botniabanan project	16	229 – 6000 m	28 passenger trains and 20 freight trains	Single-track railway tunnel, parallel evacuation tunnel*	Rural area
The City Tunnel project	1	6000 m	420 passenger trains	Two parallel single-track tunnels	City area, 2 under-ground stations
The Hallandsås project	1	8600 m	104 passenger trains and 35 freight trains	Two parallel single-track tunnels	Rural area
The Kiruna project	1	3300 m	8 passenger trains and 24 freight trains	Single track railway tunnel, parallel evacuation tunnel*	Rural area
The Nygård Tunnel project	1	3030 m	120 passenger trains and 50 freight trains	Double-track railway tunnel, parallel evacuation tunnel*	Rural area
The Ådalsbanan project	8	180 – 4538 m	31 passenger trains and 21 freight trains	Single-track railway tunnel, parallel evacuation tunnel*	Rural area
* Evacuation tunnel generally exists only for tunnels longer than 1000 m.					

Each interview was initiated by asking each respondent to describe the decision-making process of the project, with particular focus on problems he/she had experienced. Emphasis was put both on the process and the outcome of decision-making. After responding to this open question, more detailed questions related to decision-making regarding safety investments, and their influence on the railway system's ability to recover from major disturbances, were posed. All questions had been distributed in advance to each respondent, and summaries of the interviews were distributed for comments afterwards. Since some of the respondents wished to remain anonymous, the projects will be referred to as project A-F (not in the same order as presented above) in the rest of the paper.

This is to avoid that individual respondent can be identified. In addition to interviews, the collected data consists of risk and safety analyses and other safety-related documentation from each project (1-8 key documents from each project).

In Sweden, the approach to risk management is traditionally inclusive and consensual (Löfstedt 2009). Decision-making regarding the design of safety measures in railway tunnels includes a number of key stakeholders, which will be further described in Section 4.1. These actors involve representatives from the Transport Administration[2] (which is the authority responsible for construction of the railway tunnel projects) and their appointed consultants, municipal building committees, and municipal rescue services. In total, the respondents consisted of six persons employed by the Transport Administration, three from municipal rescue services, five from municipal building committees, and two consultants. One of these consultants had been involved to some extent in all of the studied projects. The transcribed interviews, as well as the safety documentation, were analysed by looking for keywords based on the four factors that formed the theoretical framework described in Section 2. These keywords related to each actor's framings of the main problems in decision-making, their perspectives on risk and safety, described disagreements, and motives for choices of specific safety investments.

One of the projects (project E) was re-planned some time after the interview had been conducted. This means that a different railway corridor was chosen in this project, and the railway tunnel that was a part of the original railway plan was therefore no longer necessary. Nonetheless, since the collected data reflected the way that decisions are made, it was still considered relevant and included in the study.

4. Results and analysis

In this section the challenges related to the provision of resilience to the railway system at the design stage of railway tunnel projects have been analysed. The analysis is based upon the theoretical framework outlined in Section 2.

4.1. Failure to Revise Assessments as New Evidence Accumulates

In several of the studied projects there was initially some uncertainty regarding what legislations to apply for issues related to safety measures and means of evacuation in railway tunnels. For ordinary buildings in Sweden means of evacuation is regulated in the Building Codes. However, railway tunnels do not fall under the definition of a 'building' in the sense of the word described in this document. Therefore, a number of other guidelines and legislations were applied, primarily the Planning and Building Act (SFS 1987:10), the Act on Technical Requirements for Construction works (SFS 1994:847) and the related ordinance (SFS 1994:1215).

An important aspect of the Planning and Building Act is the requirement for an approved building permit. It is the municipal building committee in the municipality where the construction will be located that approves the building permit before the construction can be taken into operation. This means that multiple administrative levels are involved in decision-making in railway

[2] The Transport Administration replaced the former Rail Administration and Road Administration in 2010, and therefore the names Transport Administration and Rail Administration will be used interchangeably throughout the paper depending on the context.

tunnel projects. On the national level the Transport Administration is the authority with responsibility for the railway infrastructure (including the building of new railway tunnels). On the local level each of Sweden's 290 municipalities has significant autonomy, for example regarding planning and building matters. Since the municipal building committee officials normally do not handle issues concerning means of evacuation in railway tunnels, they appointed the municipal rescue service as their expertise. This means that local actors, particularly the municipal rescue services, gained a prominent position in decision-making at the design stage of railway tunnel projects. See Figure 1 for an overview of the key stakeholders involved in decision-making at the design stage of railway tunnel projects.

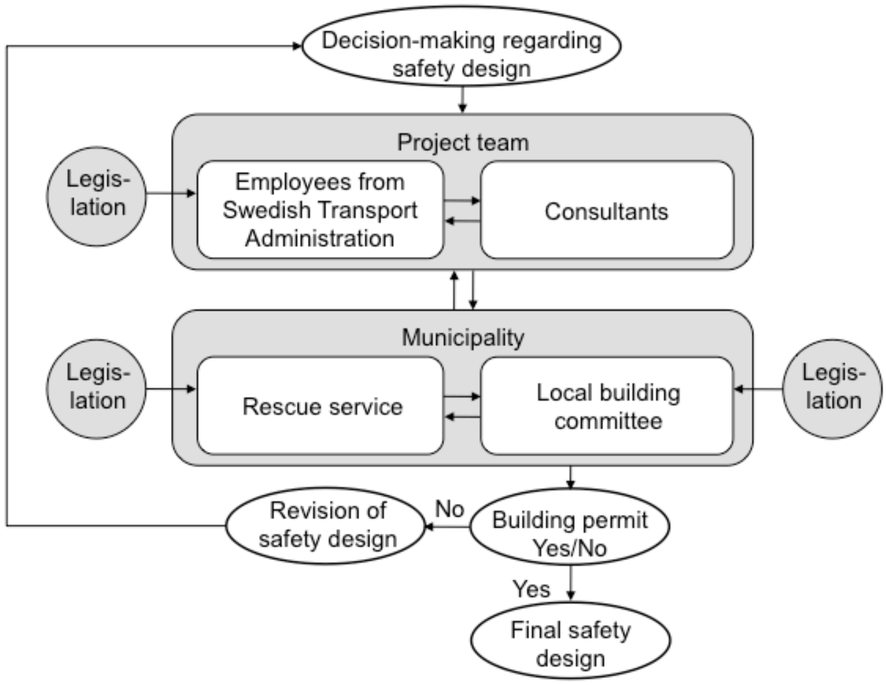

Figure 1. Schematic outline of the key stakeholders involved in the decision-making process in railway tunnel projects

One of the difficulties in applying the above-mentioned regulations was that they do not contain any verifiable safety level. For example the Ordinance on technical requirements for construction works (SFS 1994:1215 4§) merely demands that constructions shall be designed to ensure that:

> 'people … in the event of a fire can evacuate or be rescued… and [that] the safety of the rescue service personnel in the event of a fire is considered'

Due to this lack of concrete safety level, the Transport Administration (previously the Rail Administration) has developed an internal handbook on safety in railway tunnels (BVH 585.30). This handbook builds upon a risk-based approach and includes quantified criteria for an acceptable level of risk. In all studied projects appointed consultants carried out the safety documentation and quantitative risk analyses (QRAs) suggested by this handbook. The use of the approach described in BVH 585.30 has, however, not been fully agreed upon by the rescue services. The respondent from the project team in project B commented this:

> 'It's a problem that the Rail Administration's handbook BVH 585.30 still has not been fully accepted by rescue services and the Rescue Service Agency… [According to them] it is not sufficient… this idea behind a risk-based approach… so even if we have shown that we on the whole have a very high level of safety it is still not enough'

The reason for this rejection of a risk-based approach was that the proposed design of safety measures, based on the QRAs, was not considered sufficient for carrying out rescue operations. For example, the distance between evacuation exits (which also function as intervention points for the rescue service) were in many cases considered too long for enabling the rescue service to intervene in the case of an accident. This difference in framing, and consequently also the difference in opinion on how to achieve an 'acceptable' level of risk, resulted in controversies in the majority of the studied projects.

An attempt to alleviate this situation was initiated by the Swedish government in 2002. Four of the authorities involved in the design of safety measures in road and railway tunnels were assigned to create opportunities for increased coordination and consensus by clarifying the requirements raised in different legislations. However, the outcome from this assignment was limited to a declaration that (Swedish National Board of Housing, Building and Planning 2005, 3):

> 'no individual law "overrules" any other law, but each of them has an individual significance…'

This means that the differences in viewpoints among the various stakeholders remained. Neither did the incorporation with Swedish law of the European Technical Specification for Interoperability (TSI) relating to safety in railway tunnels in 2007 eliminate disagreements in the projects. Whereas the Transport Administration regarded the TSI as a standard that should be followed literally, the municipal actors only considered this document as prescribing a minimum level of safety measures.

Consequently, these diverse viewpoints created significant problems in this type of multi-organisational setting where none of the involved actors possessed the superior authority to make a final decision. A result of diverse perspectives was that the various stakeholders were unable to reach an agreement regarding what type of evidence that should be taken into account. The project team referred to the outcome from quantitative risk analyses as a demonstration of an 'acceptable' level of risk. In their view, the low probability of failures in railway tunnels implied no need for further investments in safety measures from a cost-benefit standpoint. The municipal actors, on the other hand, adopted more a deterministic point of view with the occurrence of an accident as the starting point for discussions. They referred to training situations that demonstrated the difficulties in undertaking rescue operations in dense smoke and considerable walking distances as a motivation for increased investments in safety measures (including shorter distances between evacuation exits).

Given these diverse types of arguments, which rested upon fundamentally different perspectives, none of them were able to revise their assessments when confronted with the other stakeholder's standpoint. This means that the essential issue for revising assessments in the face of new evidence was the stakeholders' ability to agree on what type of facts that should be seen as legitimate. As will be described in the next section, these diverse viewpoints created deadlocks in decision-making in many projects.

4.2. Breakdowns at the Boundaries of Organisational Units

Due to the different roles and responsibilities among the various stakeholders, the problems associated with design of safety measures were framed differently. This resulted in disagreements, for example regarding the distance between evacuation exits. These evacuation exits need to be located at regular intervals in the tunnel in order to ensure the possibility to evacuate safely in the case of an accident and to enable rescue operations.

Each additional exit implied significant costs for the Transport Administration, and from an economic point of view an excessive number of such exits was consequently not desired. In order to estimate an 'acceptable' distance between exits, the Transport Administration therefore spent considerable resources on quantitative risk analyses in each project. Based on these analyses, a proposed design of safety measures in each tunnel was presented, which required an approved building permit from the municipal actors. However, with reference to the Civil Protection Act (SFS 2003:778), the rescue services insisted on supplementary measures for safety and rescue equipment to be designed into each tunnel. These demands were raised in addition to the measures that were proposed in the design by the Transport Administration. For example, water pipe systems, smoke ventilation and rescue operation vehicles were demanded. As a consequence, some respondents from the Transport Administration considered that the municipal rescue service gained unreasonable influence over the decision-making process. One of the respondents from the project team in project D expressed that:

> 'they [the municipal actors] have somewhat kidnapped the building permit'

In this way members of the project teams experienced that the Transport Administration was trapped in a double bind. On the one hand, the consequence of agreeing upon the demands from the municipal actors would be increased costs. This was not only the case for the specific project, but also for future projects where the same amount of additional safety measures would be demanded (which will be further described below). On the other hand, disagreements with the municipal actors would result in delays of the project, which consequently also would imply increased costs. This means that the respondents from the Transport Administration experienced that no matter what actions they took, they would lead to undesired outcomes. But also the respondents representing the municipal actors experienced that they were trapped in a double bind, albeit for different reasons. Instead of purely financial risks, they suffered from a 'blame game'. This means that they on the one hand did not want to be held responsible for delaying the project by disapproving the building permit. The reason for this was that the railway tunnel constituted an important infrastructure project for the local community. On the other hand they neither wanted to be blamed for having approved the construction of a tunnel with an unacceptably low level of safety in case an accident would occur. One of the representatives from the municipal building committee in project B expressed that:

> 'you don't want to witness that you have made an erroneous decision, and then one day an accident occurs, which ultimately resonates that the … [municipal building committee in the municipality] had made an unwise decision'

These double binds consequently led to breakdowns of the decision-making process, resulting in severe deadlocks in some of the projects. In order to reconcile these double binds (and to attain an approved building permit), the project teams in several projects accepted some of the demands raised by the municipal rescue services. One of the measures resulting from such demands involved a water supply system to the tunnels. According to the interviewed consultant this was first demanded by the rescue service in a project called Åsa (prior to the studied projects). Following this agreement the rescue services in subsequent projects also demanded this type of water supply system, with reference to project Åsa. In this way, project Åsa had established a 'precedent', i.e. a new standard for what level of safety measures that should be incorporated into new tunnels.

To some extent the same kind of precedents were established for other kinds of safety measures as well, such as the distance between evacuation exits. This distance was contested in all of the studied projects, and in most of them the Transport Administration suggested a significantly longer distance between these exits than demanded by the municipal actors. For example, the initial suggestion from the Transport Administration in project C was a distance of 1000 m between evacuation exits, whereas the municipal actors demanded 200 m. A similarly large difference in opinion about this distance existed in project D, which resulted in delays of the project. This controversy was eventually resolved by an agreement between the director-generals of the Rail Administration (subsequently the Transport Administration) and the Rescue Service Agency, who decided upon a distance of 500 m for most of the tunnels in the project. This agreement was explicitly intended to apply only to project D. However, in the succeeding project B this distance was nonetheless regarded as a precedent and the same distance between evacuation exits was applied.

Consequently, once a decision was reached in one project, the same agreement was used as a benchmark in several subsequent projects. Several respondents from the project teams showed an awareness of the risk of establishing new precedents in their project. In other words they saw a need to be restrictive with agreeing upon the demands raised by the rescue service. For example, the respondent from the project team in project B described that:

> 'You [the project team] become a bit restrained… if we say 'yes' in a specific project… for example regarding mobile smoke ventilation, then you know that… this has an impact for the rest of [the railway tunnel projects in] Sweden as well'

In this way the large impact from decisions reached in previous projects created pressure on the stakeholders in each new project. As further described in the next section, the project teams were therefore unwilling to recognise these precedents as a basis for decision-making.

4.3. Past Success as a Reason for Confidence

Due to the establishment of precedents, the amount of safety measures increased gradually for successive projects. However, with reference to the low probability of accidents in railway tunnels, the project teams did not share the municipal actors' view of the need for increased safety investments. The project teams therefore opposed the establishment of precedents, and from their point of view the lack of previous serious accidents was taken as a reason for confidence. For example, one of the consultants pointed out that accidents in railway tunnels as a matter of fact are very rare, and that:

> '…you need to consider the probability of an accident occurring in the first place... [There are] Some actors in society [that] must not interfere with this, because they do not understand probabilities… they do not know how safe this is…'

This resistance against an increased level of safety in railway tunnels was expressed by the safety officer of the Rail Administration (subsequently the Transport Administration) in a statement from 2008. In this statement he emphasised that the established precedents should not be recognised as having any significance for future projects (Swedish Rail Administration 2008, 2):

> 'Previous agreements on higher demands are irrelevant and shall not be ruling. The Rail Administration has in several cases agreed upon solutions with a higher level of safety than required in current regulations. From rescue services and from the Rescue Service Agency it has been claimed that since the Rail Administration in several cases previously has accepted higher levels of safety, they should be regarded as precedents. The standpoint of the Rail Administration is that the process that has preceded these deviations does not in any way meet the demands that can be raised on a precedent. This is particularly the case given that the Rail Administration has not agreed on these demands due to safety reasons, but primarily in order to minimise the risk of delays in projects.'

In addition, the establishment of precedents downplayed the role of QRAs as a basis for decisions in the projects. For this reason several respondents from the project teams expressed dissatisfaction with the decision-making process. For example, one of the respondents questioned the value of carrying out different types of analyses, including QRAs, as a basis for determining the distance between evacuation exits. This was due to the large impact on the final decision from agreements reached in previous projects. This respondent (from the project team in project B) pointed out:

> 'If we propose 500 meters, then the rescue service feel confident… and then we know that this will be approved, although it is not a distance that has resulted from an analysis… so you start to wonder why we are doing these analyses…'

Due to this discontent with the decision-making process several respondents were willing to find ways to avoid future controversies in decision-making in railway tunnel projects. This will be further described in the next section.

4.4. Fragmented Problem Solving Process that Clouds the Big Picture

In order to avoid future controversies and double binds several respondents argued for creating a less fragmented decision-making structure in railway tunnel projects. In particular, these respondents desired that some questions, such as the distance between evacuation exits, should not be decided on the local level in each project. Rather, they considered that these matters should be determined on the national level. For the municipal actors, this desire stemmed from their perceived lack of competence or resources for making decisions in this type of questions. This was pointed out by one of the respondents from the building committee in project B:

> 'We have constantly asked for national directives, and perhaps national control of the decisions, in this type of projects. It is not an individual municipality's opinion… that should determine this. We do not have the knowledge to do that.'

Respondents from the Transport Administration also wanted to establish a more centralised decision-making process. In other words they wished to reduce the strong influence from the municipal actors on the design of safety measures in each tunnel project. The reason for this was primarily that the demands on additional safety investments raised by the different municipal rescue services contributed to delays of many projects. The Transport Administration therefore wanted to settle specific requirements for those safety measures that were regarded as common for all railway tunnels. The respondent from the project team in project D argued that:

> 'Some questions related to safety and rescue operations are generic for the whole country…. These issues should be managed centrally… but the rescue services are also involved [in the decision-making process], and they are not organised on a centralised basis'

Consequently, by transferring many decisions to the national level the strong influence from the municipal actors on the design of safety measures in each tunnel project would be reduced. In addition to the establishment of double binds this strong influence from local actors also had a large impact on the focus of attention in decision-making in the projects. Since the rescue services are organised on a local basis in each municipality, they mainly raised questions related to local aspects. For example, these questions related to the ability to intervene in the case of an accident in the tunnels. Important questions from a regional or national perspective, on the other hand, were given limited attention in the decision-making processes. In particular, the ability of the railway system to return to normal operation in the face of failures, i.e. the system's resilience, did not gain significant attention in the studied projects.

One of the opportunities for increasing resilience of the railway system relates to the selection of tunnel type and means of evacuation. Different tunnel types have different means of evacuation, and they provide different potentials for adaptation and recovery in the event of major disturbances. Means of evacuation can either be provided by a parallel evacuation tunnel (see Figures 2a and 2b), or, for tunnels consisting of two parallel single-track tunnels, by using the unaffected tunnel (see Figure 2c).

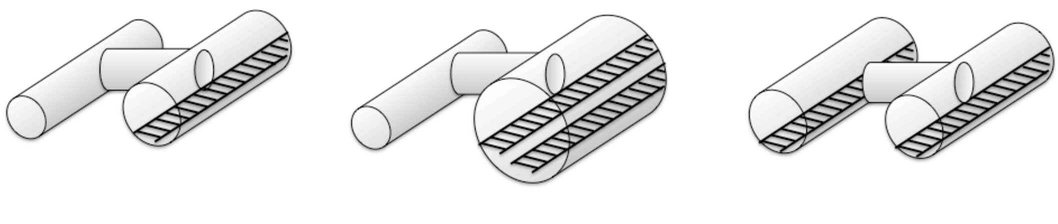

Figure 2. Schematic illustration of different designs of means of evacuation in railway tunnels (walking paths beside the tracks not illustrated in the figures). a) Single-track tunnel with separate evacuation tunnel b) Double-track tunnel with separate evacuation tunnel. c) Two parallel single-track tunnels (means of evacuation provided by the unaffected tunnel)

If a major disturbance occurs in a tunnel the latter type of tunnel design provides a possibility to use the unaffected tunnel tube, albeit with a restricted traffic flow (provided that only one of the parallel tunnel tubes is affected). In contrast, if a tunnel designed with a separate evacuation tunnel is affected no traffic is possible until this tunnel is completely restored. This is because the evacuation tunnel is not possible to use for railway traffic.

Four of the studied projects were designed with a smaller evacuation tunnel. In these projects it was noted that technical constraints required that the diameter of the evacuation tunnel had to be constructed of almost the same size as a normal railway tunnel. This means that if it had been made somewhat larger, these tunnels would be possible to use if an accident would leave the primary tunnel unavailable. As a result the railway link would have gained a significantly better ability to return to normal operation after major disturbances. Some of the respondents from the project teams recognised the vulnerability of this design. For example, the respondent from project E pointed out that:

> 'Preferably it should be possible to operate the evacuation tunnel… If we have an incident which forces us to close [the tunnel] it would lead to large consequences…'

According to the respondents from the project team in project D, the construction of full-sized evacuation tunnels would only imply negligible additional costs. Nonetheless, when the project team raised this issue, the higher-level manager of the Transport Administration rejected this solution. This was described by one of the respondents from the project team in project D:

> 'When we make them [the evacuation tunnels] this big, we believe it would be natural to prepare for putting tracks in them, that is, to make them full-sized, but the [higher-level managers of the] Rail Administration said no to that, they were not willing to take the extra cost'

The findings presented in the previous sections consequently show that local aspects of each tunnel gained priority over the role that each tunnel plays from a regional or national perspective. Even though each tunnel constitutes an important part of an entire railway section, which in turn constitutes a link in a larger network, a fragmented view of the dependencies characterising the railway system was adopted. To a large extent this stemmed from the prominent position of local actors, who mainly raised issues of local interest. Each new tunnel project therefore essentially became a local matter, which distracted focus from the bigger picture of the system's functionality. As a result, decisions were made at the local level in each project, but had an impact on the resilience of the railway system at the regional and national levels.

5. Discussion

In the analysis of challenges related to providing resilience to the railway system presented in this paper significant focus of attention was devoted to gaining understanding of the local rationality of each stakeholder. For this reason an exploratory case study approach was adopted. The inevitable downside of this approach is that only a limited number of respondents formed the empirical data. Since railway tunnel projects typically run over a period of 10-20 years, few of the respondents therefore had been involved in the projects from their beginning. This may potentially invite weaknesses to the reliability of the analysis. However, the risk of significant biases from this factor is seen as low, based on the triangulation that was possible by interviewing different stakeholders in the same project.

The results from the case study revealed that decision-making in Swedish railway tunnel projects is highly political and largely influenced by power relations between the different stakeholders. In this respect, the case study shares a number of similarities with Flyvbjerg's analysis of a Danish city-planning project, in which he points out that 'power relations are active and decisive in the design phase of the project' (1998, 52). The diverse roles and responsibilities among the different actors involved in the railway tunnel projects created disagreements in the decision-making process. From these differences in viewpoints, deadlocks emerged in several projects due to the double binds that the central stakeholders experienced. As described in Section 4.4., several respondents desired to transfer some of the decisions from the local to the national level in order to reduce these double binds. However, since further consideration of this suggestion would require a thorough assessment of the legal framework, this is clearly outside the scope of the paper.

The double bind experienced by the project teams related to the risk of delays and increased costs (which confirms the perspective on risk as events that are threatening the project, not emanating from it, as concluded by Boholm 2010 in a study of other types of railway projects in Sweden). The double bind experienced by the municipal actors, on the other hand, was related to blame avoidance (see Hood, Rothstein and Baldwin 2001 and Hood 2002 for further discussions of blame avoidance strategies). The deadlocks stemming from these double binds are somewhat untypical for the Swedish risk management approach, which traditionally is consensus-oriented and involves little conflict (Löfstedt 2009). Due to these double binds, and the large influence from local actors on the decision-making process, significant focus of attention was directed towards local aspects of each tunnel. This resulted in a restricted consideration of the system's resilience on the regional and national levels.

As for all complex systems, these findings illustrate that local actions typically have global consequences (Heylighen, Cilliers and Gershenson 2007; Axelrod and Cohen 2000). Several authors have emphasised the importance of analysing this link between local interactions and their global effects. For example, Dekker (2011, 170) claims that failures in complex systems emerge through 'the interaction between diverse, interacting and adaptive entities whose micro-level behaviours produce macro-level patterns'. The results from this study highlight the relationship between decision-making in railway tunnel projects and its impact on the system's resilience. The paper therefore contributes to increased understanding of the way that the micro-macro connection in complex socio-technical systems is manifested (cf. Vaughan 1996), i.e. how behaviours at the local levels of a system influences characteristics on the system level.

6. Conclusions

From the results presented in this paper it can be concluded that resilience of the railway system gain limited attention at the design stage of new railway tunnels in Sweden. The theoretical framework adopted for analysing the decision-making process in this type of projects was based upon insights from the fields of resilience engineering and risk governance. These fields typically focus on somewhat different aspects of risk management. Nonetheless, both fields give emphasis to four similar factors that are important for managing risks in complex systems. These four factors formed the theoretical framework for analysing the decision-making process in the studied railway tunnel projects. The results from this study confirmed that these factors give rise to challenges to the risk management process, and their empirical value can therefore be strengthened. With these generic factors as a point of departure, additional challenges related to the provision of resilience to the Swedish railway system were identified. In particular, the results showed that diverse roles and perspectives among the different actors resulted in disagreements and deadlocks in the majority of the studied projects. The multi-level and multi-actor decision-making setting created a situation in which the key stakeholders experienced that they were trapped in different double binds. In this way power relations between the different stakeholders were highly influential in shaping the decision-making process. The significant impact from local actors in this process contributed to a restricted consideration of the system's resilience on the regional and national levels. This kind of cross-scale interaction between different levels of a socio-technical system has been identified as an important challenge for understanding and managing a system's resilience (McDonald 2006; Woods 2006). The findings of this study confirm this type of challenges, and provide insights into their manifestation by contributing with increased understanding of the way that micro-level decisions affect macro-level characteristics of complex socio-technical systems.

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References

Almklov, P.G., and S. Antonsen. 2010. The Commoditization of Societal Safety. *Journal of Contingencies and Crisis Management* 18, no. 3: 132-144.

Amin, M. 2001. Toward Self-Healing Energy Infrastructure Systems. *IEEE Computer Applications in Power* 14, no. 1: 20-28.

Ansell, C., A. Boin, and A. Keller. 2010. Managing Transboundary Crises: Identifying the Building Blocks of an Effective Response System. *Journal of Contingencies and Crisis Management* 18, no. 4: 195-207.

Axelrod, R., and M.D. Cohen. 2000. *Harnessing complexity: organizational implications of a scientific frontier*. New York: Basic Books.

Birkland, T.A., and S. Waterman. 2009. The Politics and Policy Challenges of Disaster Resilience. In *Resilience Engineering Perspectives, Volume 2: Preparation and Restoration*, edited by C.P. Nemeth, E. Hollnagel and S. Dekker. Farnham: Ashgate Publishing Limited.

Boholm, Å. 2010. On the organizational practice of expert-based risk management: A case of railway planning. *Risk Management* 12, no. 4: 235–255.

Boholm, Å., H. Corvellec, and M. Karlsson. 2012. The practice of risk governance: lessons from the field. *Journal of Risk Research* 15, no. 1: 1-20.

Boin, A., L.K. Comfort, and C.C. Demchak. 2010. The rise of resilience. In *Designing Resilience: Preparing for extreme events*, edited by A. Boin, L. K. Comfort and C. C. Demchak. Pittsburgh: University of Pittsburgh Press.

Cedergren, A. 2011. *Challenges in Designing Resilient Socio-technical Systems: A Case Study of Railway Tunnel Projects*. Edited by E. Hollnagel, E. Rigaud and D. Besnard, *Proceedings of the fourth Resilience Engineering Symposium*. Paris: Presses des MINES.

Cilliers, P. 2001. Boundaries, Hierarchies and Networks in Complex Systems. *International Journal of Innovation Management* 5, no. 2: 135-147.

de Bruijne, M., and M. van Eeten. 2007. Systems that Should Have Failed: Critical Infrastructure Protection in an Institutionally Fragmented Environment. *Journal of Contingencies and Crisis Management* 15, no. 1: 18-29.

de Bruijne, M., A. Boin, and M. van Eeten. 2010. Resilience: Exploring the Concept and Its Meanings. In *Designing Resilience: Preparing for extreme events*, edited by A. Boin, L. K. Comfort and C. C. Demchak. Pittsburgh: University of Pittsburgh Press.

Dekker, S. 2005. *Ten Questions About Human Error: A New View of Human Factors and System Safety*. New York: CRC Press.

Dekker, S. 2011. *Drift into failure: from hunting broken components to understanding complex systems*. Farnham: Ashgate Publishing Limited.

Flyvbjerg, B. 1998. *Rationality and power: democracy in practice*. Chicago: The University of Chicago Press.

Heylighen, F., P. Cilliers, and C. Gershenson. 2007. Complexity and Philosophy. In *Complexity, science and society*, edited by J. Bogg and R. Geyer. Oxford: Radcliffe Publishing Limited.

Hollnagel, E., and E. Rigaud, eds. 2006. *Proceedings of the Second Resilience Engineering Symposium*: Paris: Presses des MINES.

Hollnagel, E., D.D. Woods, and N. Leveson, eds. 2006. *Resilience Engineering: Concepts and Precepts*. Aldershot: Ashgate Publishing Limited.

Hollnagel, E., C.P. Nemeth, and S. Dekker, eds. 2008. *Resilience Engineering Perspectives: Remaining Sensitive to the Possibility of Failure*. Vol. 1. Aldershot: Ashgate Publishing Limited.

Hollnagel, E., F. Pieri, and E. Rigaud, eds. 2008. *Proceedings of the Third Resilience Engineering Symposium*. Paris: Presses des MINES.

Hollnagel, E. 2011a. Epilogue: RAG - The Resilience Analysis Grid. In *Resilience Engineering in Practice: A Guidebook*, edited by E. Hollnagel, J. Paries, D.D. Woods and J. Wreathall. Farnham: Ashgate Publishing Limited.

Hollnagel, E. 2011b. Prologue: The Scope of Resilience Engineering. In *Resilience Engineering in Practice: A Guidebook*, edited by E. Hollnagel, J. Paries, D.D. Woods and J. Wreathall. Farnham: Ashgate Publishing Limited.

Hollnagel, E., J. Paries, D.D. Woods, and J. Wreathall, eds. 2011. *Resilience Engineering in Practice: A Guidebook*. Farnham: Ashgate Publishing Limited.

Hollnagel, E., E. Rigaud, and D. Besnard, eds. 2011. *Proceedings of the fourth Resilience Engineering Symposium*. Paris: Presses des MINES.

Hood, C., H. Rothstein, and R. Baldwin. 2001. *The government of risk: understanding risk regulation regimes*. Oxford: Oxford University Press.

Hood, C. 2002. The Risk Game and the Blame Game. *Government and opposition: a journal of comparative politics* 37, no. 1: 15-37.

International Risk Governance Council (IRGC). 2005. White paper on risk governance: Towards an integrative approach. Geneva: International Risk Governance Council (IRGC).

International Risk Governance Council (IRGC). 2009. Risk Governance Deficits: An analysis and illustration of the most common deficits in risk governance. Geneva: International Risk Governance Council (IRGC).

Johansson, J., H. Hassel, and A. Cedergren. forthcoming. Vulnerability analysis of interdependent critical infrastructures: case study of the Swedish railway system. *International Journal of Critical Infrastructures*.

Kramer, R.M. 2005. A Failure to Communicate: 9/11 and the Tragedy of the Informational Commons. *International Public Management Journal* 8, no. 3: 397-416.

Leveson, N., N. Dulac, D. Zipkin, J. Cutcher-Gershenfeld, J. Carroll, and B. Barrett. 2006. Engineering Resilience into Safety-Critical Systems. In *Resilience Engineering: Concepts and precepts*, edited by E. Hollnagel, D.D. Woods and N. Leveson. Aldershot: Ashgate Publishing Limited.

Lidskog, R., Y. Uggla, and L. Soneryd. 2011. Making Transboundary Risks Governable: Reducing Complexity, Constructing Spatial Identity, and Ascribing Capabilities. *AMBIO: A Journal of the Human Environment* 40, no. 2: 111-120.

Little, R.G. 2002. Toward More Robust Infrastructure: Observations on Improving the Resilience and Reliability of Critical Systems. *Proceedings of the 36th Annual Hawaii International Conference on System Sciences 2003*: 58-66.

Little, R.G. 2004. A socio-technical systems approach to understanding and enhancing the reliability of interdependent infrastructure systems. *International Journal of Emergency Management* 2, nos. 1-2: 98-110.

Löfstedt, R.E. 2009. *Risk Management in Post-Trust Societies*. London: Earthscan.

Macchi, L., T. Reiman, E. Pietikäinen, P. Oedewald, and N. Gotcheva. 2011. DISC model as a conceptual tool for engineering organisational resilience: Two case studies in nuclear and healthcare domains. In *Proceedings of the fourth Resilience Engineering Symposium*, edited by E. Hollnagel, E. Rigaud and D. Besnard. Paris: Presses des MINES.

McDonald, N. 2006. Organizational Resilience and Industrial Risk. In *Resilience Engineering: Concepts and Precepts*, edited by E. Hollnagel, D.D. Woods and N. Leveson. Aldershot: Ashgate Publishing Limited.

McDaniels, T., S. Chang, K. Peterson, J. Mikawoz, and D. Reed. 2007. Empirical Framework for Characterizing Infrastructure Failure Interdependencies. *Journal of Infrastructure Systems* 13, no. 3: 175-184.

McDaniels, T., S. Chang, D. Cole, J. Mikawoz, and H. Longstaff. 2008. Fostering resilience to extreme events within infrastructure systems: Characterizing decision contexts for mitigation and adaptation. *Global Environmental Change* 18, no. 2: 310-318.

Nemeth, C.P., E. Hollnagel, and S. Dekker, eds. 2009. *Resilience Engineering Perspectives, Volume 2: Preparation and Restoration*. Farnham: Ashgate Publishing Limited.

Ostrom, E. 1999. Coping with Tragedies of the Commons. *Annual Review of Political Science* 2, no. 1: 493-535.

Renn, O., A. Klinke, and M. van Asselt. 2011. Coping with Complexity, Uncertainty and Ambiguity in Risk Governance: A Synthesis. *AMBIO: A Journal of the Human Environment* 40, no. 2: 231-246.

Rinaldi, S.M., J.P. Peerenboom, and T.K. Kelly. 2001. Identifying, Understanding, and Analyzing Critical Infrastructure Interdependencies. *IEEE Control Systems Magazine* 21, no. 6: 11-25.

Rochlin, G.I. 1999. Safe operation as a social construct. *Ergonomics* 42, no. 11: 1549-1560.

SFS 1987:10. *Plan- och bygglagen (Planning and Building Act)*. Stockholm: Svensk författningssamling.

SFS 1994:847. *Lag om tekniska egenskapskrav på byggnadsverk (Act on Technical Requirements for Construction works)*. Stockholm: Svensk författningssamling.

SFS 1994:1215. *Förordning om tekniska egenskapskrav på byggnadsverk (Ordinance on Technical Requirements for Construction Works)*. Stockholm: Svensk författningssamling.

SFS 2003:778. *Lagen om skydd mot olyckor (Civil Protection Act)*. Stockholm: Svensk författningssamling.

Slovic, P. 2001. The risk game. *Journal of Hazardous Materials* 86, nos. 1-3: 17-24.

Starbuck, W.H., and F.J. Milliken. 1988. Challenger: Fine-tuning the odds until something breaks. *Journal of Management Studies* 25, no. 4: 319-340.

Sundström, G., and E. Hollnagel. 2006. Learning How to Create Resilience in Business Systems. In *Resilience Engineering: Concepts and Precepts*, edited by E. Hollnagel, D.D. Woods and N. Leveson. Aldershot: Ashgate Publishing Limited.

Swedish Civil Contingencies Agency. 2011. *Ett fungerande samhälle i en föränderlig värld: Nationell strategi för skydd av samhällsviktig verksamhet [A functioning society in a changing world: National strategy for protection of essential societal* activities]. Karlstad: Swedish Civil Contingencies Agency.

Swedish National Board of Housing, Building and Planning. 2005. *Kartläggning av det legala ramverket – Delprojekt 1, bilaga till regeringsuppdrag Personsäkerhet i tunnlar [Survey of the legal framework - Subproject 1, appendix to the government assignment Safety in tunnels)*. Karlskrona: Swedish National Board of Housing, Building and Planning.

Swedish Rail Administration. 2007. *BVH 585.30. Personsäkerhet i järnvägstunnlar: Handbok för analys och värdering av personsäkerhet i järnvägstunnlar (Safety in railway tunnels: Handbook for analysis and evaluation of safety in railway tunnels)*. Borlänge: Swedish Rail Administration.

Swedish Rail Administration. 2008. Banverkets ställningstagande avseende säkerhet i tunnlar (The Rail Administration's standpoint regarding safety in tunnels). Borlänge: Swedish Rail Administration.

van Asselt, M., and O. Renn. 2011. Risk governance. *Journal of Risk Research* 14, no. 4: 431-449.

Vaughan, D. 1996. *The Challenger Launch Decision: Risky Technology, Culture, and Deviance at NASA*. Chicago: The University of Chicago Press.

Weick, K.E., K.M. Sutcliffe, and D. Obstfeld. 1999. Organizing for High Reliability: Processes of Collective Mindfulness. *Research in Organizational Behavior* 21:81-123.

Woods, D.D. 2003. Creating Foresight: How Resilience Engineering Can Transform NASA's Approach to Risky Decision Making. In *Testimony on The Future of NASA for Committee on Commerce, Science and Transportation. John McCain, Chair, October 29, 2003*. Washington D.C.

Woods, D.D. 2006. Essential Characteristics of Resilience. In *Resilience Engineering: Concepts and Precepts*, edited by E. Hollnagel, D.D. Woods and N. Leveson. Aldershot: Ashgate Publishing Limited.

Woods, D.D., and M. Branlat. 2011. Basic Patterns in How Adaptive Systems Fail. In *Resilience Engineering in Practice: A Guidebook*, edited by E. Hollnagel, J. Paries, D. D. Woods and J. Wreathall. Farnham: Ashgate Publishing Limited.