Challenges in Designing Resilient Socio-technical Systems: A Case Study of Railway Tunnel Projects

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Challenges in Designing Resilient Socio-technical Systems: A Case Study of Railway Tunnel Projects

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Abstract. This paper presents a case study of decision-making at the design stage of a socio-technical system where resilience at the global level of the system was constrained by the local perspectives adopted by the different stakeholders. The study is based on interviews with key decision-makers involved in the design stage of six railway tunnel projects in Sweden. The results show that differences in roles and perspectives among the involved actors created double binds and led to extensive discussions and deadlocks during decision-making in the majority of the studied projects. In these projects agreements could only be reached by relying on the outcome from previous railway tunnel projects, regardless differences in project-specific aspects. A significant impact from local actors during decision-making increased the potential for sub-optimizations and resulted in a limited focus on the system's resilience from a regional and national perspective. The findings point at the need for more emphasis in the field of resilience engineering on cross-organisational aspects in order to gain increased understanding of the challenges related to improving resilience of socio-technical systems.

1 INTRODUCTION

The novelty of resilience engineering largely lies in the perspective it provides on safety (Hollnagel, 2008). In particular this perspective includes the view that both failures and successes are the outcome of normal performance variability. This view of failures as the flip side of success motivates the study of processes under normal conditions and not only when things have gone wrong, which is taken as a starting point for this study.

Many contributions to the field of resilience engineering focus on the strategies and abilities to adapt and survive within individual teams and organisations. However, as pointed out by Woods (2006: p. 23) "the resilience of a system defined at one scale depends on influences from scales above and below". This means that analysis of the wider context in which most organisations exist, including the interactions between multiple actors of a socio-technical system, may also provide interesting insights to the field of resilience engineering. The influence from this kind of multi-organisational interplay on the resilience of a socio-technical system is laid already during its design and construction. The objective of this paper is therefore to adopt a resilience engineering perspective for analysing the design stage of a socio-technical system. The system under consideration in this study is railway tunnel projects, and the paper is based on the following question: In what ways do decision-making during the design stage of railway tunnel projects affect the resilience of the railway system?

Several definitions and characterisations of factors contributing to or depriving resilience from a system have been suggested in the resilience engineering literature. According to Woods (2003), resilience engineering is built upon insights derived from a number of factors that have been observed as contributory to many accidents. These factors include:

1. An organization takes past success as a reason for confidence instead of digging deeper to see underlying risks.
2. Failure to revise assessments as new evidence accumulates.
3. Drift toward failure as defences erode in the face of production pressure.
4. Fragmented problem solving process that clouds the big picture.
5. Breakdowns at the boundaries of organizational units.

These factors have provided the basis for analysis in this paper. In this way the study has some similarities to the work by Hale and Heijer (2006), although their data is mainly collected from railway maintenance operations. Before moving into the analysis some background information of the railway tunnel projects and an outline of the different actors holding lead roles in the decision-making processes will be described.

2 DECISION-MAKING IN RAILWAY TUNNEL PROJECTS

The results presented in this paper are based on an interview study conducted between 2008-2010 including a total of 18 persons involved in the design stage of six railway tunnel projects in Sweden. In total, the six railway tunnel projects encompass 28 tunnels, which represents the majority of railway tunnels currently under design or construction.

Decision-making regarding safety measures in railway tunnel projects involve a number of different actors. In Figure 1 the central actors involved at the design stage of this process in Swedish railway tunnel projects are schematically illustrated. The actor responsible for construction of railway tunnel projects is the Swedish Transport Administration (previously Swedish Rail Administration). In addition, external consultants are appointed to the project teams since the competences on safety and risk analysis that are required in the guidelines for tunnel construction are limited within the Swedish Transport Administration. Design of safety measures is based on the guidance provided in a handbook (BVH585.30) prescribing a risk-based approach.

In order to construct buildings in Sweden (including railway tunnels) a building permit needs to be approved by the local building committee. This requirement leads to several implications for the decision-making process regarding the design of railway tunnels. Since satisfactory means of evacuation is required in order to gain a building permit, the local building committee in the municipality where the tunnel will be constructed needs to approve the proposed means of evacuation. Due to the unusual type of construction, employees within the building committee often do not feel comfortable in approving the building permit for this type of object. Therefore, representatives from the local rescue service are appointed as the municipality's expert opinion for assessing the requirements for means of evacuation. In this way, representatives from the local rescue service attain a central role in decision-making regarding the design of safety measures in railway tunnels. This structure of the decision-making process, and the different legislations applied, leads to a situation involving several perspectives and standpoints. As a consequence agreements and final decisions become difficult to reach. In some projects severe deadlocks emerge due to differences in standpoints between the various actors.

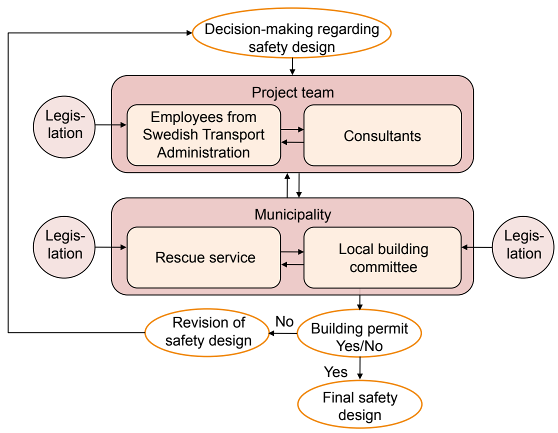

Fig 1. Schematic outline of the decision-making process in railway tunnel projects

3 RESULTS AND ANALYSIS

The five factors presented by Woods (2003) have been used as a basis for analysis of the decision-making process outlined in Figure 1. The insights derived from this analysis are presented in the following sections.

3.1 An Organisation Takes Past Success as a Reason for Confidence

In the majority of the studied projects the same design solutions of safety measures that had been adopted in previous projects were used as a basis for decision-making, regardless differences in for example traffic flow, type of traffic and existence of underground stations. This indicated that past success was taken as a reason for confidence. The explanation to this outcome can be found in the complicated decision-making process that will be outlined in this section, involving extensive negotiations between different actors characterised by significant discrepancies in goals and perspectives.

One of the main issues that resulted in intense discussions between the involved actors during the design stage of the railway tunnels concerned the distance between evacuation exits. Each additional evacuation exit implied significant costs for the Transport Administration, and an excessive number of such exits were consequently not desired from an economic point of view. The Transport Administration therefore spent considerable resources on probabilistic risk analyses in each project in order to estimate an adequate distance between exits for their proposed design.

As mentioned previously, the rescue service came to hold a prominent position in the decision making process regarding the design of the tunnels. Based on their governing legislations, they demanded additional measures for safety and response equipment to be designed into each tunnel, supplementary to the measures that were proposed in the design by the Transport Administration. As a consequence, the Transport Administration experienced that the local rescue service "kidnapped the building permit" and at the same time trapped the Transport Administration in a double bind. On the one hand, the consequence of agreeing on the demands from the municipal actors (the building committee and rescue service) would be increased costs, not only for the specific project, but also in future projects where the same amount of additional safety measures would be demanded. On the other hand, disagreements with the municipal actors would result in delays of the project, which consequently also would imply increased costs. But also 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" where they on the one hand did not want to be held responsible for delaying the project by disapproving the building permit, since 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 the unlikely event of a severe accident once the tunnel had been taken into operation. In order to feel confident in the approval of the building permit, the municipal actors demanded that the safety investments had to be of the same type and amount as in recently designed or constructed railway tunnels in other municipalities. In this way, the final decisions on the distance between evacuation exists could in several project only be reached by adopting the same distance that had been decided upon in previous projects (i.e. they became "precedents"), regardless a number of differences between the projects.

3.2 Failure to Revise Assessments as New Evidence Accumulates

The results presented previously, showing that severe deadlocks emerged in the majority of the projects, reflects the fact that revising assessments is not something that any of the actors were easily willing to do. However, this failure to revise assessments was not only based on an inability to identify new evidence. Instead, a large part of the problem rested on the fact that the different actors were unable to agree on what type of evidence that should be considered as legitimate. The Transport Administration referred to the results showed in risk assessments in order to demonstrate (and justify) an "acceptable" level of risk, whereas the rescue service referred to training situations showing the difficulties in carrying out rescue operations in an environment with considerable walking distances in dense smoke. In this way, the different types of evidence rested on fundamentally different perspectives, and none of the actors were able to revise their assessments when the other actor presented new evidence. Whereas the Transport Administration argued for the low probability of failures in railway tunnels, implying no need for further investments from a cost-benefit standpoint, the rescue service argued from a deterministic perspective, taking the occurrence of an accident as a starting point for discussions. The critical question was therefore not the ability to revise assessment in the face of new evidence, but rather to agree on what type of evidence to take into consideration. As a consequence much of the "evidence" presented by the different actors played a minor role in several projects. The decision-making process rather focused more on what level that was deemed acceptable by all stakeholders, regardless the outcome of different analyses. As pointed out by one of the interviewees "the risk analysis became meaningless as a basis for decision-making" (since this was not regarded as sufficient evidence by the rescue service). As described above, decision-making was in many cases instead a result of negotiation and reliance on the outcome from previous projects.

3.3 Drift Toward Failure as Defences Erode in the Face of Production Pressure

Another of the five factors described by Woods is drift toward failure. Dekker (2006) points out that drift toward failure is one of the greatest residual risks to today's safe socio-technical systems, and suggests that a role for resilience engineering is to find leverage for additional progress on safety through a better understanding of the processes leading to this drift. Hollnagel and Woods (2006) remark that the concept of drift builds upon several metaphors, and should therefore not be taken literally. A suitable conceptualisation of drift should focus on the effects stemming from a combination of incremental unnoticed or seemingly harmless decisions, actions or changes that eventually can lead to large impacts on the system.

For complex socio-technical systems with extensive lifetimes such as railway tunnels, this type of incremental changes or decisions of various parameters will inevitably occur over the system's lifetime. For example, it is unlikely that a constant level will be maintained in terms of the type of goods that are transported in the tunnels, the flow of trains and passengers, the type of trains and cars, the speed of trains, etc. However, the assumptions made during design in the studied projects were based on a relatively static view of each tunnel. This means that many solutions for means of evacuation presupposed that the technical equipment would remain in more or less the same state throughout the tunnel's lifetime. The limitation of this assumption was manifested in one of the projects, where some of the emergency equipment malfunctioned already before the tunnel was taken into operation.

A thorough study of the way that a slow migration contributes to the erosion of the system's defences, e.g. due to tradeoffs between production and safety, requires a longitudinal study of the system during its operational phase. The data collected for this study (that only involved tunnels at the design stage) is therefore insufficient for assessing the occurrence and extent of such stepwise changes and the way that they potentially can lead to failure. Nonetheless, resilience engineering represents an important contribution to an increased understanding of how failures emerge by focusing on the dynamic properties of socio-technical systems, although few practical tools or techniques for how to detect and prevent this drift have so far been presented.

3.4 Fragmented Problem Solving Process that Clouds the Big Picture

A fourth factor described by Woods (2003) as influential for a system's resilience is fragmented problem solving. The way that a complex system such as a railway tunnel is described depends on the manner in which the boundaries of what constitutes the system and what constitutes its environment are defined. Each railway tunnel constitutes a sub-system of a specific railway section, which in turn constitutes a sub-system of an entire railway network. This means that if the boundaries are drawn in one way, a certain number of problems are identified and dealt with. If drawn in another way, other problems may come to the fore. In the studied projects the system boundary was rather narrowly defined around the physical tunnel itself, without much consideration of the way that properties of each tunnel influence the functioning of the entire railway system. Consequently discussions about the ability of the railway system to return to normal operation in the face of disturbances, i.e. resilience in its literal sense, did not gain any significant attention in the studied projects.

This fragmented problem solving can be explained as a result of the local perspectives adopted by the involved actors. Even though project staff was employed from the Transport Administration (that has a national interest in the functioning of the entire railway system), they were employed locally to a specific project. Furthermore, the need for an approved building permit and the central role of the rescue service resulted in a large emphasis during decision-making on local aspects of the tunnel, at the cost of its influence on the bigger picture of the railway network. The frames of reference adopted by the different stakeholders, influenced by their differences in goals and governing legislations, therefore constrained the ability to consider resilience of the system at a regional and national level.

3.5 Breakdowns at the Boundaries of Organisational Units

Although the decision-making process suffered from both intra-organisational and inter-organisational challenges, the most significant breakdowns occurred at the boundaries between different organisations (which should be rather evident from previous sections). These problems, such as the experience of different types of double binds and deadlocks during decision-making, typically gain limited attention within the resilience engineering field. As pointed out by Mendonça (2008: p. 36) "Cross-scale interactions generally refer to within-organization interactions, though it may be possible that cross-organization interactions are also relevant to resilient performance". From the results presented in this paper it can be concluded that these cross-organisational aspects doubtlessly have an impact on the resilience of an entire socio-technical system. An important future challenge of resilience engineering therefore involves a more thorough emphasis on the way that the kind of cross-organisational aspects identified in this paper influence the resilience of complex systems.

4 CONCLUSIONS

Resilience engineering sheds significant light upon the need to take dynamic properties of a system into consideration. This is an essential starting point for understanding how and why complex systems sometimes fail. Furthermore, many contributions to the resilience engineering field highlight the kind of actions and decisions that are taken in any operational system, which normally lead to success but from time to time have unintended long-term side-effects. However, limited focus has been directed to the interplay between different organisations in socio-technical systems in the area of resilience engineering, and in particular to the design stage of such systems. The importance of these cross-organisational interactions was manifested in the studied projects. In the analysis of decision-making at the design stage of railway tunnel projects from a resilience engineering perspective it was revealed that differences in roles and perspectives created double binds and resulted in a reliance on the outcome from previous projects. The conclusion from this study was that the significant impact from local actors during decision-making resulted in a restricted attention to the resilience of the system on a regional and national level. Consequently, increased understanding of the way that resilience is created on the level of a socio-technical system requires further studies of the way that micro level decisions lead to macro level effects.

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