ASSESSING RESPONSE SYSTEM CAPABILITIES OF SOCIO-TECHNICAL SYSTEMS

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Abstract

Our society is becoming more and more dependent upon the reliable function of a number of vital socio-technical systems. These systems are often being referred to as critical infrastructures, or lifeline systems, indicating their importance for supporting a nation's economy and social well-being. In the present paper a method is presented for assessing the capability of those actors involved in restoring socio-technical systems after strains affecting its technical systems. Parallel ongoing work by the authors, not presented here, emphasises on technical systems' interdependencies. Together, these approaches address the issue of vulnerability analysis of socio-technical systems. The presented method is derived from the theories of both systems thinking and resilience engineering. The method has been applied in a preliminary study of a socio-technical system, namely the Swedish railway system. The method systematically identifies the system elements by evaluating the system both under normal operation and under strain. The actors directly involved in the restoration of the technical system, referred to as the response system, are identified and selected for in-depth studies. The overall objective of the study is to assess the time required for the response system to restore the technical system after strains of varying magnitude, by introducing the concept of response curves. The curves reveal response system capabilities and their limits, i.e. the magnitude of strain for which the actors can no longer cope. It is concluded that the proposed method is both applicable and valid in the efforts of assessing response system capabilities of socio-technical systems.

Introduction

The society is becoming more and more dependent upon the reliable function of a number of vital systems, e.g. electrical power, telecommunications, water supply, banking and finance, and information technology (e.g. de Bruijne and van Eeten, 2007; Rinaldi et al., 2001). These systems are often being referred to as critical infrastructure systems or lifeline systems (McDaniels et al., 2007), indicating their importance for supporting a nation's economy and social well-being (Little, 2004). The increasing demands for flexibility and availability have

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lead to continuous improvements of the efficiency of critical infrastructures. However, as a result of the increasing efficiency under normal operations, the infrastructures are becoming more and more interdependent (e.g. Amin, 2001; Stoop and Thissen, 1997), i.e. mutually dependent on one another. Because of these interdependencies, failure in one system can propagate to other systems leading to so called cascading failures (e.g. Little, 2002; Rinaldi et al., 2001), and result in not so easily foreseeable vulnerabilities.

Much of the complexity characterising critical infrastructures depends on the interactions between physical networks and actor networks, that "collectively form an interconnected complex network where the actors determine the development of the physical network, and the physical network structure affects the behaviour of the actors" (Verwater-Lukszo and Bouwmans, 2005, p.2379). Critical infrastructures can therefore be described as socio-technical systems. The approach presented in this paper, together with ongoing research by the authors focusing on vulnerability studies of the technical aspects of socio-technical systems, constitutes a comprehensive approach for assessing vulnerability of such systems.

A recent example illustrating the vulnerability of the railway system is an incident occurring during rush hour on October 15 2008 when a train between Malmö and Lund, Sweden, tore down a traction power line. Although a minor strain, it resulted in severe delays for all trains in the region, affecting thousands of travellers. Hundreds of passengers on board the trains were not allowed to evacuate because of the uncertainty whether the traction power was shut off or not. Passengers had to wait for about 4 hours before they were evacuated, which according to the Swedish Rail Administration is believed to depend on a lacking communication between those actors responsible for restoring the system. Hence, the consequence for the system as a whole is highly dependent upon the capacity and performance of these actors restoring the system. The example highlights an important aspect in assessing the vulnerability of a critical infrastructure; the system's ability to return to normal operation after different types and magnitudes of strain. The method presented in this paper aims at assessing this ability.

From a crisis management perspective the aim of the research is to give guidance in the mitigation and preparedness phases, i.e. appropriate actions and activities before an accident occurs in order to mitigate the likelihood and/or the consequences of an undesired event.

Analysis of socio-technical systems from a systems thinking approach

There are several problems with undertaking a study of a socio-technical system, mainly due to the large number of actors and technical elements involved. In order to take all relevant aspect and interdependencies characterising such complex system into consideration, it is the authors' opinion that the system's vulnerability should be analysed from a systems thinking standpoint.

Much of the emergency response and disturbance management are in the hands of different operation and maintenance actors, and it is therefore not fully satisfying only taking the technical aspect into consideration when assessing the vulnerability of technical infrastructures (e.g. Appicharla, 2006). Thissen and Herder (2003) argues that methods that can handle the socio-technical nature of infrastructure systems, enabling analysis from different perspectives, should be developed. According to Little (2005), analysis of the relationships between technology, people and organisations that are required to provide continued function of our vital infrastructure systems should be based on a holistic approach, which is a view shared by the authors. Furthermore, systems that consist of large numbers of elements and relations, with nonlinear interactions, time delays and unintended feedback loops that can lead to unpredictable behaviour are referred to as complex systems (Axelrod and Cohen, 2000). Thus, the socio-technical systems that are emphasised in this study can be viewed as complex systems in accordance with the definitions given above. In an effort towards taking all these aspects into consideration, the use of ideas from the area of systems thinking is advocated.

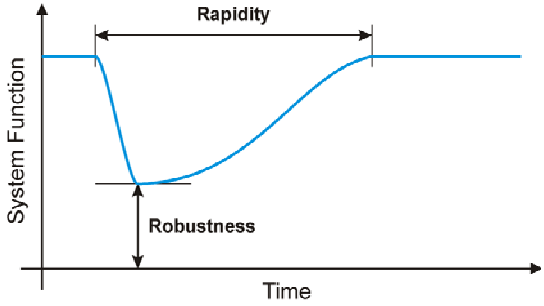
The fundamental idea behind systems thinking is to study systems as wholes rather than their elements in separation, in order to address complexity (Checkland, 2006). A system is defined as a number of elements with relations between these elements, forming a whole. A system boundary represents the distinction between what is part of the system and what is part of its environment, and the boundary must be defined with respect to the elements that have an influence on the problem situation being studied (Jackson, 2000).

Resilience engineering

Resilience engineering is broadly about creating ability for complex systems (e.g. socio-technical systems) to recover after being exposed to strain. This is in line with the purpose of the present study, therefore ideas from the area of resilience engineering is used. Resilience is described by Hollnagel et al. (2006, p.4) as "the ability of systems to anticipate and adapt to the potential for surprise and failure". However, as resilience engineering is a discipline under formation, numerous definitions of the concepts can be found in the literature, and according to Westrum in Hollnagel et al. (2006, p.65) the concept is "a family of related ideas, not a single thing". Another way of describing resilience is as a "[complex system's] capacity to absorb shocks while maintaining function." (McDaniels et al., 2008, p.310). This definition is adapted by the authors. For a more thorough overview and use of the concept of resilience, see e.g. Hollnagel et al. (2006).

McDaniels et al. (2008) refers to two key properties for describing resilience: robustness and rapidity, see Figure 1. Robustness refers to a system's ability to withstand a certain amount of stress without suffering degradation or loss of function. Rapidity refers to a system's speed of recovery of function from an undesired event and back to a desired level of function. McDaniels et al. (2008) also point out that resilience can be improved by both ex-ante and ex-post decision-making, stemming from both risk mitigation activities undertaken before an incident and response activities taken following the incident. Vulnerability is here seen as an antonym to the two aspects of resilience emphasised by McDaniels et al., i.e. a low degree of vulnerability corresponds to a high degree of robustness and rapidity. It is hence the authors' view that risk and vulnerability analysis are useful tools in the efforts to design more resilient systems.

Figure 1. Resilience curve for a system affected by strain. The inverted loss of system function is a measure of the robustness, and the system's speed of recovery to a desired system function is a measure of the rapidity (Figure based on McDaniels et al., 2008).

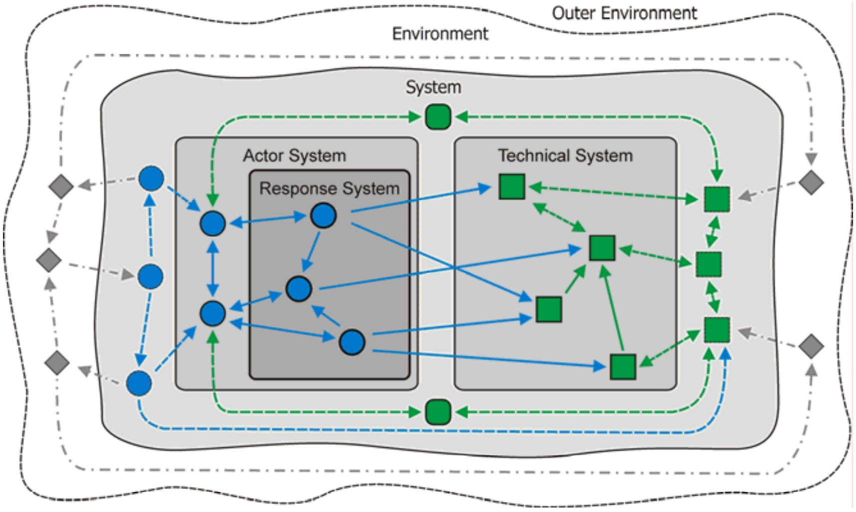


Method for identifying response system capabilities

As a first step for assessing the response system capability of a socio-technical system, corresponding to the rapidity aspect in accordance with the concept of resilience discussed in the previous section, the elements and interdependencies characterising the system must be fully described by the creation of a system model. The system model enables the identification of elements and relationships that are critical in many types of studies. The presented method is generic, and can therefore be used for different types of socio-technical systems. Later in this paper, a preliminary study is described where the method has been applied to a section of the Swedish railway system.

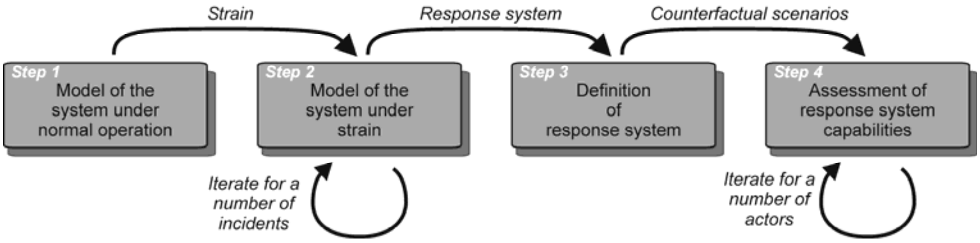
An important aspect of the system model is to explicate system boundaries. A system can be seen as an element of a larger system, and likewise, an element of the system can be decomposed into a number of smaller subsystems depending on the frame of reference. Therefore, when looking at the world in terms of systems, a number of hierarchical levels can be identified depending on the resolution of the study (Skyttner, 2005). Consequently, a consideration of the appropriate level of abstraction is essential (c.f. Rasmussen, 1985) when constructing a system model. In our general system model, four significant system boundaries can be identified. The first one is between the outer environment and the environment; this system boundary reveals what is regarded as possibly influential to the system behaviour and what is regarded as non-influential. The second system boundary is between the environment and the system, defining which parts that are regarded as part of the system and which parts that is regarded as possibly influential to the system behaviour. The socio-technical system is then divided into two subsystems, the actor system and the technical system, which are distinguished from the system by defining those elements that directly supports the function of the system. In addition, a fifth system boundary is defined with respect to the aim of the present study. This border is defined between the actor system and those actors that are directly involved in restoring the technical system under strain, i.e. the response system. For other methods focusing on response systems from a systems approach see e.g. Uhr et al. (2008).

Figure 2. Schematic view of a socio-technical system.



The method involves a systematic approach for identifying those actors who have a direct impact upon the restoration of the technical system. These actors are referred to as the response system and constitute a subset of the actor system, see Figure 2. The method for mapping the system, steps 1 and 2, and identifying and assessing the capability of the response system, steps 3 and 4, is described in Figure 3. The method involves iterative processes in order to capture all the relevant aspects of the system. Steps 3 and 4 can be substituted depending on the aim of the study.

Figure 3. The four steps forming the method.



Step 1. Model of the system under normal operation. The first step for assessing the response system's capability is to construct a model of the system under normal operation. This is achieved by identifying those elements that are considered most important for the purpose of the study, i.e. those elements that interact to produce the behaviour that is subject for investigation (Jackson, 2000). Although it is the response system that is in focus in the present paper, it is important to map a larger part of the system, since the actors are both highly interconnected with each other and connected to the technical part of the system. The main reason for the construction of a model of the system under normal operation is that the model facilitates the understanding of the system's behaviour (Jackson, 2000), and that it functions as a common mental model of the system for the participants in a study (c.f. Senge et al., 1994).

Step 2. Model of the system under strain. In this step an incident, e.g. some type of strain affecting the technical system, is described. Depending on the type and magnitude of strain affecting the system, the incident described may result in some degree of loss of the system's function. The actors necessary for restoration of the technical system are identified, and added to the actor system in the model that was created in step 1. A number of incidents are described through an iterative process, and for each incident additional actors are added to the system model. For each new incident, the number of actors that has not been identified in previous incidents will decrease and eventually reach zero, whereby the mapping process is considered complete.

Step 3. Definition of response system. Those actors that play an active part in the restoration of the technical system are referred to as the response system and constitute a subset of the actor system. The boundary between response actors and other actors, identified in step 2, is distinguished by the means of a definition of the response system. The response system is here defined as those actors who either have a professional role in restoring the system, or those who facilitate the restoration by carrying out actions that are directly aimed at restoring the system. It should be noted that under normal operation most of the response system is usually seen as a latent part of the system, i.e. most of the response actors do not have an active role in the system under normal operation, but become involved as the system deviates from this desired normal state.

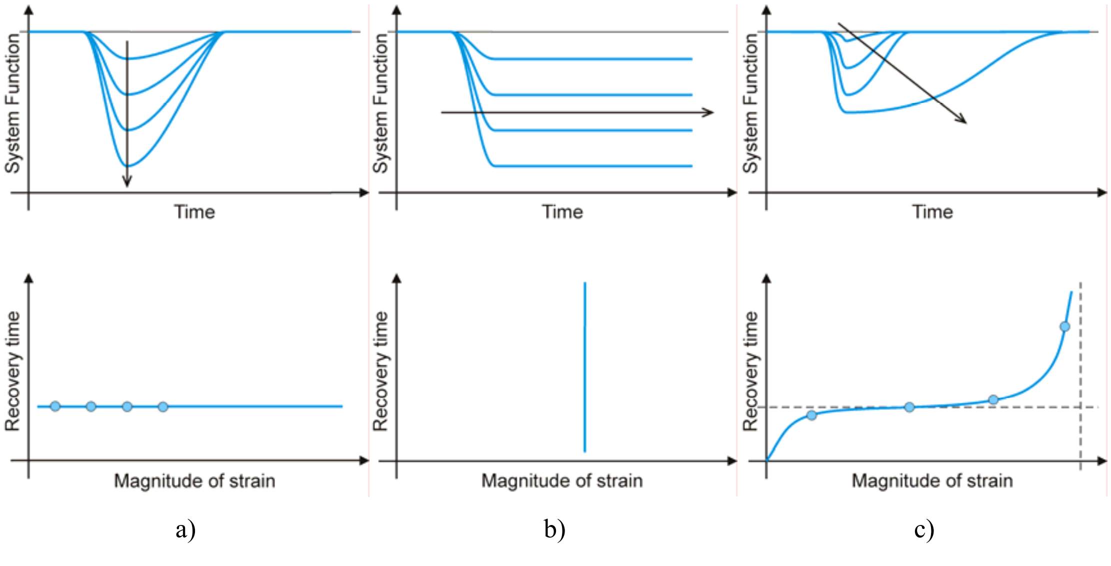
Step 4. Assessment of response system capabilities. The overarching purpose of the present paper is to study the way that the system is restored and brought back into normal operation after being affected by strain. Thus, this step focuses on the response actors and in quantifying their capability, basing our view of response system capability in accordance with Jönsson et al. (2007). Since the system as a whole is known, the relationships that directly or indirectly may influence the response actors' capability are taken into account. By systematically running through incidents and counterfactual scenarios, the time for restoration given different types and magnitudes of strain affecting the technical system can be assessed. This information is used for creating response curves, which are more thoroughly discussed in the next section.

Response curves

The time required for the technical system to recover is highly dependent upon the response actors' ability to restore the system after strains of varying magnitude. This corresponds to the rapidity aspect, illustrated in Figure 1. In contrast to the system mapping that was carried out by qualitatively identifying elements and relations, the study of the response system addresses the issue of quantitatively assessing capabilities. For this estimation, some of the real incidents, which were used as a basis for the system mapping in the previous section, are here used as a starting point. The real incidents are used for developing hypothetical scenarios, using what Abrahamsson et al. (2008) refers to as counterfactual scenarios. Counterfactual scenarios are variations of real incidents. For example, in the case of a railway system the real incident could involve a derailment of one car; then a counterfactual scenario may be derailment of two cars. The counterfactual scenarios are then used to assess actors' ability of repairing the technical system, and more specifically to estimate recovery times, with the main interest in finding the limit of the actors' capabilities.

For the representation of the recovery times, the authors introduce the concept of response curves. In general, a response curve depicts the time it takes to restore a system with respect to varying magnitudes of strain. Naturally there will be different response curves for different types of strains and for different actors. Figure 4 depicts response curves and how they are closely related to the concept of resilience. Here the system function degradation and the magnitude of strain are assumed to have a linear relationship, i.e. that all magnitudes of strain result in a corresponding linear loss of function, in order to simplify the reasoning. In reality, the linear relationship might not always be true, for instance some systems may tolerate a certain level of strain before the system function is affected. The figures show two asymptotic extremes (a and b), and one realistic response curve (c). In Figure 4a) the capacity of managing increasing strains is sufficient, and the time for recovery is thus constant for all magnitudes of strains. In Figure 4b), there is insufficient capacity of managing increasing magnitudes of strains (or actually managing the strain at all), leading to longer restoration times, which is indicated by the vertical line in the response curve. In Figure 4c), the expected resilience curve for a real incident and the corresponding response curve with the two asymptotes sketched as dotted lines are presented. These asymptotes depict where the recovery time is unaffected (the horizontal line), and the border of the actor's capacity (the vertical line), given the strain. The awareness of these asymptotes simplifies the interpretation of real response curves with respect to the response system's coping capability and where a limit is reached.

Figure 4. Resilience curve (above) and corresponding response curve (below) for a) recovery time independent of magnitude of strain, b) infinite response time for different magnitudes of strain, and c) the expected resilience and response curves for real incidents.



There are several benefits with the use of response curves. First of all, the response curves make it easier to identify at which magnitude of strain the response organisation will reach a critical point in terms of capacity for restoring the system. Secondly, by combining different actors' response curves for the same type of strain, it can be differentiated which actor that is or will become a bottleneck for handling the strain. Thirdly, the possibility to compare response curves for the same actor, but for different types of strain, gives an indication of what types of strains the actor has been designed to respond to.

An approach similar to our proposed response curves is discussed by Woods and Wreathall (2008). Their approach is based on an analogy with stress-strain plots in order to characterise an organisation's ability to handle increasing demands, which has been applied to an emergency department by Wears et al. (2008). Stress-strain plots, i.e. the kind of plots resulting from analysing material structures' ability to withstand increasing loads of strain, are characterised by two regions; an elastic region and a plastic region. In the elastic region the material stretches uniformly under increasing strains, whereas in the plastic region the material fractures and a failure point is eventually reached. They argue that the same patterns can be identified for organisations under strain. The response curves presented in this paper aims at illustrating a similar type of relationship between increasing strain and demand as discussed by Woods and Wreathall (2008), but here applied to the response system's ability to restore a technical system after increasing loads of strain. However, we are interested in the shape of the curve and not only the elastic and plastic regions as included in their work, i.e. we are interested in how the ability of the response system changes with respect to a variety of magnitudes of strain and not only the identification of a failure point.

Empirical study of the Swedish Railway system

The method presented in this paper has been used in a preliminary study for a section of the Swedish railway system. The railway section is a 258 km long double track railway between the cities of Gothenburg and Hallsberg, and is highly important for the functioning of the Swedish railway transport system since it connects the two largest cities in Sweden, Stockholm and Gothenburg. The Swedish railway system is administrated and operated by the Swedish Rail Administration, which is also responsible for traffic management. The trains utilizing the railway infrastructures are owned and operated by private companies.

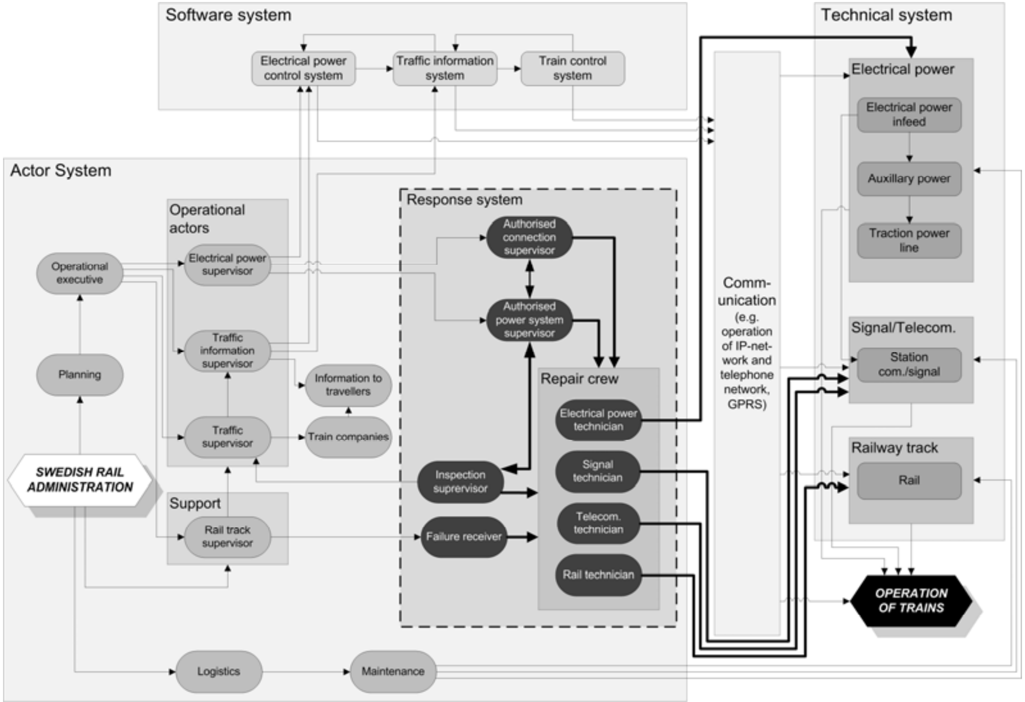
The empirical study was prepared by creating a record of incidents that have occurred on the railway section. These incidents were found by studying documentation of events that have lead to technical system degradations during the last three years. Since the number of incidents that have occurred on the specific railway section is limited, data from other incidents that have occurred elsewhere in the Swedish railway system was also included in this record. From this collection of data, relevant real incidents were categorized by type of event, magnitude of strain, affected technical system and restoration time, and were used to give an initial set of reference for the study.

The study followed the four steps, as illustrated in Figure 3, in a workshop session including 4 employees from the Swedish Rail Administration, representing different divisions within the company. The selection of the participants was based on two requirements: comprehensive view of the railway system and knowledge and experience from restoration of the technical railway system after incidents.

The first step, i.e. identification of elements (actors and technical systems) and their relations, forming the railway system under normal operation, was carried out after agreeing on the appropriate level of abstraction (c.f. Rasmussen, 1985). The identified elements and their relations were depicted in a system model, iteratively evolved until all participants agreed upon the acquired system model. The system model in this step broadly consists of the actors necessary for the normal daily operation of the railway system, the software management systems necessary for the operation as it is an interface between the actor system and the technical systems, and the technical systems required for the operation of trains.

The second step began by describing a real incident that has occurred on the studied railway section for the participants. The incident involved a strain consisting of a torn down traction power line, due to a tree that had fallen towards the railway track. Based on this description, the participants identified those actors who had been involved in the restoration of the technical systems. These actors and their relationships were added to the model of the system under normal operation, resulting in a model of the system under strain. The system model in Figure 5 consists of those elements and relationships that are necessary for the operation of the system both under normal operation and under strain. By using a systematic approach, the probability of accidentally excluding important elements and relationships in the next step of the study is minimised.

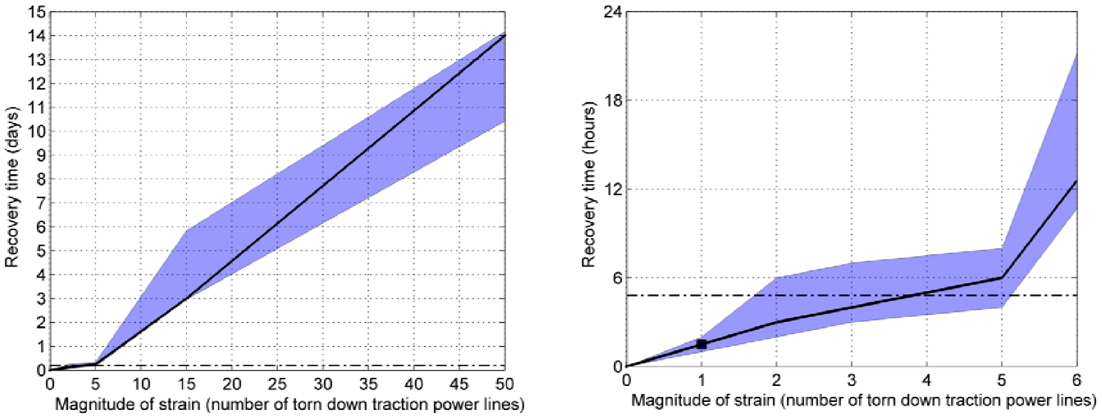
Figure 5. The system model for the system under strain. The Swedish Rail Administration is responsible for enabling a safe and reliable operation of trains. This requires operational actors, software management systems, and a technical infrastructure. In the case of a strain affecting the technical system, a response system is activated in order to restore the system to normal state of operation as quickly as possible.



Based on the definition of the response system given previously, a system boundary was drawn between those actors active under normal operation, and those actors who played an active role in restoring the system after the specific strain. In Figure 5, a dashed black border surrounds the response system. The response system consists of personnel responsible for on-site management and different types of repair crews.

After the identification of what constitutes the response system, the next step was to assess the response system's ability to restore the technical systems after strains, i.e. the construction of response curves. The incident used for the response system mapping, step 2, was then used as a basis for counterfactual scenarios. The counterfactual scenarios consisted of scenarios causing more strain on the traction power system, with respect to more traction power lines torn down. The participants estimated the response time for the counterfactual scenarios, taking into account resource capacities and other limiting factors. In Figure 6 the response curve from the preliminary study is presented. The figure shows the combined response curve for all the actors involved, i.e. it depicts the estimation of the time for the full recovery of all the technical systems for the given type of strain. In Figure 6a two clear regions can be identified, one between zero to five torn down traction power lines and one between five to fifty torn down traction power lines. The first region (strain zero to five) indicates were only the normal response teams for the given railway section is involved, and the second region (strain five to fifty) when response teams from other railway section are activated and utilised for the recovery of the technical systems. For the given maximum magnitude of strain, the response capacity of the entire Swedish Rail Administration is more than sufficient, resulting in the linear relationship with no apparent vertical asymptote that would reveal insufficient capacity of managing increasing magnitudes of strains. Figure 6b shows the response curve for the limited recovery time of up to 24 hours and the magnitude of strain of up to six torn down traction power lines. This figure more clearly reveals the capacity of the response system for the given railway section, and more significantly that there is an indication of a limitation of the response capacity when the magnitude of strain goes beyond five torn down traction power lines.

Figure 6. The response curve is a function of the estimated recovery time with respect to the magnitude of strain in a) from 0 to 50 and b) from 0 to 6 torn down traction power lines. The estimated most likely recovery time is shown as a black solid line, and estimated maximum and minimum recovery times are shown as a shaded field. The strain constitutes of trees falling on the railway section, tearing down traction power lines. The horizontal asymptote is a dashed black line. The base case incident is indicated as a black square in b).



a) b)

The preliminary study revealed that the approach of firstly mapping the system and then using response curves in workshop sessions with participants knowledgeable of the social-technical system under study is a sound approach. Further studies are required in order to draw more specific conclusions regarding the response systems' capabilities.

Discussion

The identification of elements and their relationships by using the systematic approach, based on systems thinking, results in a system model. This model is used in the present paper to draw a relevant system boundary around the response system. Due to the size and complexity of the system under study, it is nearly impossible to identify the entire system given a limited time frame. In the preliminary empirical study we therefore emphasised on mapping the technical system and the actors directly involved both under normal operation and under strain. The system mapping has two significant purposes; to make sure that all participants share a common mental model of the system under study and to facilitate the correct identification of the response system, including the relationships that can influence their behaviour. The application of the system mapping method, steps 1 and 2, during the workshop session confirmed the usefulness and strengthened our belief in the presented approach. However, in future studies it would be beneficial to cross-check the acquired system model with other employees from the Swedish Rail Administration. This approach would facilitate a way to test the validity of the acquired system model more stringently.

The response curves resulting from using steps 3 and 4 of the method reveal a number of interesting characteristics that can be valuable for preparedness planning of the response system capability of socio-technical systems. First of all, it is the authors' belief that most real response curves will have a region where the recovery time has a fairly linear relationship with increasing magnitudes of strain. In the most extreme case this region is a horizontal asymptote in accordance with Figure 4a. This region is important since it reveals the magnitude of strain for which the response system has a sufficient capacity, or, in other words, has been designed to handle. Secondly, at some magnitude of strain there is a point, or rather a region, where the response time drastically increases for a small additional increase of the magnitude of strain. In the most extreme case this region is a vertical asymptote as shown in Figure 4b. By including counterfactual scenarios with magnitudes of strain that are above those of normal, well known, incidents it is possible to identify this region. The region reveals where the response system reaches a limit for which it no longer can cope with the strain. The only remedy for this situation is if there is a possibility to use external capacity. Thirdly, a region can be identified where a small initial increase in magnitude of strain will lead to an initial rapid increase in recovery time before a plateau is reached. This region indicates the time required before any restoration can be initiated, e.g. the time for transportation to the site, the need for a specific scarce type of resource in order to carry out the restoration, or the time for notification of response actors about the incident. Variations in the level of this plateau between different response actors and for different types of strain is valuable, e.g. for deployment or location of different actors and resources. The preliminary study revealed that two of these three significant indicators actually are present for real systems.

The response curves for different types of response actors and for different types of strains can be used for comparing and assessing for what types of strains there is appropriate capacity to handle and for which there is not, in a proactive manner before actual incidents reveal critical limitations. Such comparisons can also reveal where limitations can be expected due to a disproportional capacity for the restoration of different technical systems, and hence for which response actors additional resources should be allocated. Another important aspect of hypothetically testing response system capabilities is to reveal the importance of having sufficient capacities, which are unnecessary under normal operation but highly critical in the recovery from incidents. Consequently, the response curves can be used as a basis for decision-making regarding the adequate capacity for restoring the technical system after different types and magnitudes of strain.

Data collected from incident investigation reports often give an indication of the time required for restoring the system for a given type and magnitude of strain, and can therefore be used to benchmark against the results obtained from the counterfactual scenarios in order increase the validity of the study.

A potential weakness of the presented method is that it at the moment only is based on historical events. By varying the magnitude of these events above what has been experienced previously, by the use of counterfactual scenarios, valuable insights regarding response system capabilities are gained. However, by not assessing other credible, not yet experienced, events there is a possibility that weaknesses in the response system is overlooked. In future studies it would thus be beneficiary to also include hypothetical events, with the aim to increase the span of events in order to, for example, find events for which response system capabilities are insufficient.

The ability for generalization of the results from the study, which typically concerns a specific geographical location, needs to be further addressed. This can done by evaluating real incidents and counterfactual scenarios for other geographical locations, and then assess if the response and the consequence would be similar. It is then possible to evaluate if the results are valid for the railway system as a whole, and not only to the specific locations where the incidents actually took place.

In ongoing work by the authors (Johansson et al., 2008), the system model is used as a starting point, but here the emphasis is on studying the vulnerability of the interdependent technical railway systems, as identified in the system model. By systematically simulating failures in one or more technical systems simultaneously, the vulnerability of the technical system as a whole, due to dependencies between the subsystems, can be studied. For this purpose, the use of recovery times, as identified through the use of response curves, is very important in achieving a realistic measure of the system’s overall vulnerability.

Future studies involve analysing organisational vulnerabilities. By using the system model as a starting point, the different actors’ ability to cope with organisational strains, such as how the lack of certain actors or poor communication affects the rapidity to restore a system after a certain strain, can be studied. For this type of study, only a limited part of the technical components will be included, while all identified actors and their relationships will play an important role. The future aim is to be able to do a comprehensive analysis of the socio-technical system’s vulnerability, bringing both the actor system and the technical system models together under the same umbrella.

Conclusions

The method presented in this paper offers a systematic approach, influenced by concepts from systems thinking and resilience engineering, for assessing the response system capability of socio-technical systems. The method involves construction of a system model, aiming at identifying all those elements that have an influence on the problem situation being studied. Based on this model, an accurate identification of those actors constituting the response system can be done. Given the focus of the present study, a comprehensive method addressing the assessment of response system capabilities was presented. The method includes the introduction of response curves, which illustrates the recovery time with respect to the magnitude of strain affecting the technical systems. These response curves facilitates the identification of both the response system capability for which the response system is designed for and the magnitude of strain for which the response capacity is insufficient, given by the two introduced asymptotes.

The present paper also includes a preliminary empirical study, aiming at evaluating the usefulness of the presented method. In order to reach more comprehensive conclusions about the response system capabilities of the Swedish Rail Administration, further studies are required. However, it is concluded that the preliminary study supports the validity and the applicability of the presented method.

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