Development of a method for studying cascading effects between critical infrastructures

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Short: A method for studying cascading effects

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Lund 2015

Utveckling av en metod för att studera kaskadeffekter mellan viktiga samhällsfunktioner
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Abstract
Most current methods for studying cascading effects rely on written sources to extract information. This thesis presents an empirical method for studying cascading effects, when little written information of the event is available. The method presented has been influenced by incident investigation methods. It has been applied on a case of flooding in south of Sweden and revised based on the results. The case study showed that the method is able to gather and structure information about cascading effects and conditions that affect the outcome of cascading effects. An advantage of this method is that it captures conditions as well as potential cascading effects.

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Summary

Most current methods for studying cascading effects rely on written sources to extract information, such as post-disaster assessments, scientific articles or media articles. This thesis presents an empirical method for studying cascading effects, when little written information of the event is available. The intended users of this method are researchers of cascading effects or, to a lesser degree, incident investigation teams or managers.

A literature review of incident investigation methods has influenced the method, thus partly building on previous research. Its main components consist of semi-structured interviews and modified STEP-diagrams, with some inclusion of counterfactual reasoning. It aims to gather information about the affected system, the consequences of that system, the type of dependency, the originating system, time and geographical extent, cascade order and conditions. Conditions are circumstances that aggravated or mitigated the effects of a cascading effect.

A case study of the floods in Malmö, August 31st 2014, showed that the method is able to gather and structure information about cascading effects and conditions that affect the outcome of cascading effects. The study consisted of six interviews with key persons within organisations, which are involved in management of critical infrastructure according to the system definitions used in this thesis. The review of the study showed some flaws in the original design; it was not feasible to gather all the desired information in one interview. Therefore the suggested method was modified slightly, so that the time and geographical extent inquiries will conducted at a later time in the process, and not during the initial interviews.

An advantage of this method is that it captures conditions, giving extra detail, as well as potential cascading effects, which can provide valuable information about suitable cascade breaking measures.

Sammanfattning

De flesta nuvarande metoderna för att studera kaskadeffekter använder sig av skriftliga källor för att samla information, såsom olycksutredningar, vetenskapliga artiklar eller nyheter. Det här examensarbetet presenterar en empirisk metod för att studera kaskadeffekter när det finns få skriftliga källor tillgängliga. Målgruppen är forskare som studerar kaskadeffekter och, till mindre grad, olycksutredningsteam eller ledare.

En litteraturstudie av olycksutredningsmetoder har influerat metoden som presenteras, därmed bygger den delvis på tidigare genomförd forskning. Dess huvudkomponenter består av semi-strukturerade intervjuer och modifierade STEP-diagram, med viss inblandning av kontrafaktiska resonemang. Målet är att samla information om det påverkade systemet, konsekvenserna i det systemet, typ av beroende, ursprungssystemet, utbredning i tid och rum, kaskadordning och *conditions*. *Conditions* är tillfälligheter som påverkade kaskadeffekten negativt eller positivt.

En fallstudie av översvämningarna i Malmö, den 31:e augusti 2014, visade att metoden klarade av att samla och strukturera information om kaskadeffekter och *conditions* som påverkade resultatet av kaskadeffekterna. Studien bestod av sex intervjuer med nyckelpersoner inom organisationer som bedriver samhällsviktig verksamhet, såsom det är definierat i det här arbetet. Studien visade på vissa brister i originalförslaget, det var inte möjligt att samla all önskad information vid ett tillfälle. Därför modifierades metoden lite, så att frågorna om utbredning i tid och rum genomförs i ett senare stadie, och inte under den första intervjun.

En fördel med denna metod är att den fångar in *conditions*, vilket ger extra detaljeringsgrad, så väl som potentiella kaskadeffekter, vilka kan förse värdefull information om lämpliga åtgärder för att bryta kaskadeffekter.

Table of contents

1 Introduction

Critical infrastructure protection is a research area that has been expanding; in Sweden the Civil Contingency Agency has put a lot of effort into developing a national strategy for protecting critical societal functions (here regarded the same as critical infrastructure) and mapping dependencies between them the last few years (Fylkner, 2009; Gellerbring, Holmgren, & Rinne, 2014). Also, in 2006 the European Union started a *European Programme for Critical Infrastructure Protection* to create a common, European, framework for protecting infrastructure (COMMISSION OF THE EUROPEAN COMMUNITIES, 2006). Further, in the U.S. there was an increased awareness of infrastructure vulnerability within the homeland security agencies after the attack on the World Trade Centre. The USA PATRIOT Act of 2001 stressed the importance of protecting critical infrastructures and redefined which ones that was to be considered critical (Moteff & Parfomak, 2004).

A part of protecting critical infrastructure involves preventing cascading effects between them. A *cascading effect* occurs when one critical infrastructure affects another, usually negatively, through dependencies between them, for example when a water supply system starts experiencing problems after a failure in the power supply system, because the pumps are dependent on electricity. Some of the important research conducted on cascading effects so far includes the work of Rinaldi et al. (2001) who developed a comprehensive theoretical framework and terminology for cascading effects between critical infrastructures (Rinaldi, Peerenboom, & Kelly, 2001). Many researchers have adopted the terminology or adapted it to their own liking, including two of the research groups below.

A Canadian research group have studied large-scale power outages in North America in great detail, using media reports and official ex post assessments (McDaniels, Chang, Peterson, Mikawoz, & Reed, 2007). However, they only study events where the electrical infrastructure is the starting point of the cascading effects (they call it infrastructure failure interdependencies), which limits the number of events that can be studied and also in large extent disregards systems that are not dependent of power.

Another approach is to search a large amount of media articles for any kind of disruption in a critical infrastructure, then analyse each result and compile into a database, which is what a Dutch research group has done (Luiijf, Nieuwenhuijs, Klaver, van Eeten, & Cruz, 2009). Their research suggests that cascading effects are quite common, but are mainly involved two sectors, the energy and the telecom sectors. This could be an effect of the search words used: *disruption(s), outage(s), blackout* and *power cut*, which are words commonly associated with these sectors. When reporting about the health sector, however, a reporter is more likely to use words like: *overcrowding, cancelled surgeries, staff shortage, medicine shortage* or similar.

What if someone wants to study the cascading effects that occurred during an event, which is badly documented or has yet to be documented? In this case the methods used by McDaniels et al. (2007) and Luiijf et al. (2009) are not applicable. Therefore, another method is needed to provide a deeper understanding of the event and the possible cascading effects related to that event.

The purpose of this thesis is to develop a method for studying cascading effects, including conditions, which can be used even if there is a scarcity of written documents. The method should be able to gather and structure information about cascading effects and its most important characteristics.

In the long run, the results from a number of case studies can be used to: identify vulnerable systems, support risk and vulnerability analysis efforts, develop an incident support tool or model cascading effects.

2 Objective & Aim

The scope of the thesis is to propose and evaluate a method for studying which cascading effects has emerged between different critical infrastructures during an event and how conditions can affect the outcome. More specifically, the objectives are to:

- Conduct a survey of the methods used in similar research areas.
- Develop a method for in-depth study of events, with the purpose of acquiring knowledge about cascading effects and the conditions associated with cascading effects. The method should focus on gathering and structuring information.
- Perform a case study, in order to apply, evaluate and revise the proposed method.

2.1 Research questions

- What characteristics should the proposed method have in order to be useful for studying cascading effects?
- What methods can be found in related research areas that can provide a basis for the method developed in this thesis?
- How should the method look like in order to take the relevant characteristics into consideration?
- Is the method capable of satisfying the relevant characteristics, and if not, what revisions are necessary?

3 Method

In this chapter, the general work process of the thesis will be presented. An overview of this process can be found in Figure 1. In the beginning of each chapter there will be a miniature of Figure 1 as a reminder. The steps included in the chapter will be marked with red. To develop a method for studying cascading effects, a general model of the phenomena needs to be developed or adopted. Then desired characteristics of the cascading effects will determine the design of the method.

In order to draw knowledge from previous research, incident investigation methods will be studied through a literature review, since it is an area closely related to what this thesis is set out to accomplish. The investigation methods are then evaluated with the ability to gather information of the desired characteristics in mind. Other information gathering methods will also be studied depending on the amount of incident investigation methods found.

The proposed method will be based on the results of the literature review and modified to fit the study of cascading effects as the phenomenon has been defined.

To test the proposed method and determine its usefulness and its ability to gather the desired information, it will be used on a small case study. This is followed by an evaluation, where the study, experiences from it and its results are discussed. Lastly the method will be revised according to the evaluation of the case study.

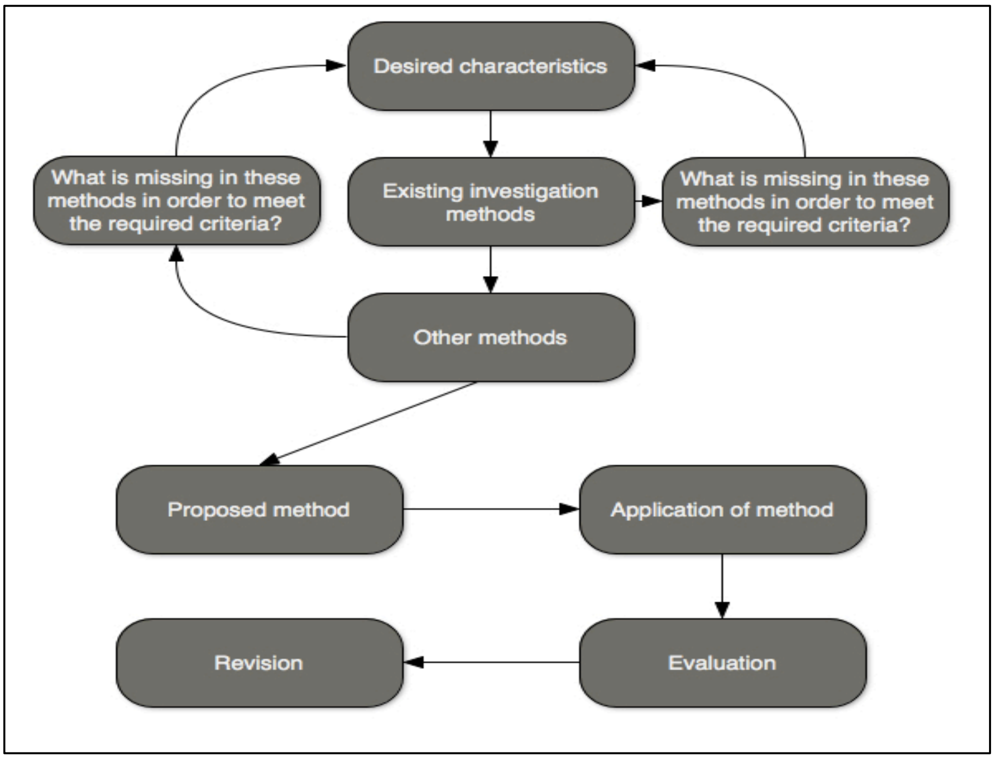
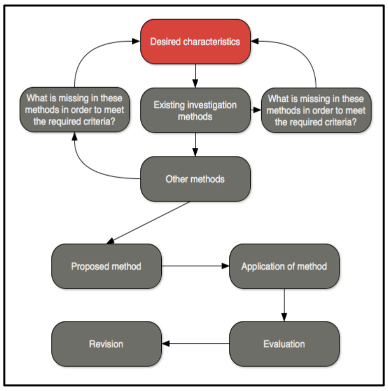


Figure 1. Work process overview. A miniature figure will be shown in the beginning of each chapter, where red marks the parts that are included in the chapter.

4 Cascading effects



There are many different opinions regarding the definition of a cascading effect, many researchers use their own, slightly different, terminology, as has been mentioned shortly in the introductory chapter. This chapter aims to provide some clarification of how the term *cascading effects* and related terminology will be used in this thesis.

The first section will describe the definition of cascading effects used in this thesis and introduce some of the core terminology. The second section will cover the different system boundaries used and compare them to other projects' definitions. The third, and last, section will introduce the desired characteristics of cascading effects and why they are important.

4.1 Definition of cascading effects

In this thesis, a cascading effect is defined in accordance with the definition used in the CascEff[1] project. It is as follows:

Cascading effects are the impacts of an initiating event where

1. System dependencies lead to impacts propagating to other systems, and;

2. The combined impacts of the propagated event are of greater consequences than the root impacts, and;

3. Multiple stakeholders and/or responders are involved.

[1] The aim of the project is to improve our understanding of the cascading effects in crisis situations to reduce the consequences of escalating incidents in complex environments. The EU project CascEff is funded via the Seventh Framework Programme. The CascEff consortium consists of eleven partners from five countries and is coordinated by SP Technical Research Institute of Sweden (CascEff, 2015). Lund University is a partner in the project.

Bullet one describes the basic requirement, but leaves the concept of system up for interpretation. It also presents the mechanism behind cascading effects, the dependency, which is the link that connects systems to each other. If two systems are affected at the same time, but there is no tangible link between them, there is no cascading effect (e.g. a polluted ecosystem and a non-functional financial transaction system).

The second bullet effectively excludes events where a system has a positive effect on another.

Bullet three, although loosely formulated and up for interpretation, encourages a societal perspective and can be used to discard cascading effects with minor societal impact (e.g. a single wrecked car caused by a cascading effect). This means that cascading effects as understood in this thesis often arises between critical infrastructures. Bullet three also provides some support in determining system boundaries, by implying a multi-organisational perspective. It also, together with bullet one, excludes cascading effects within the same system, since only one stakeholder would typically be involved (e.g. a short circuit damaging a logic component in a mobile phone tower, rendering it non-operational).

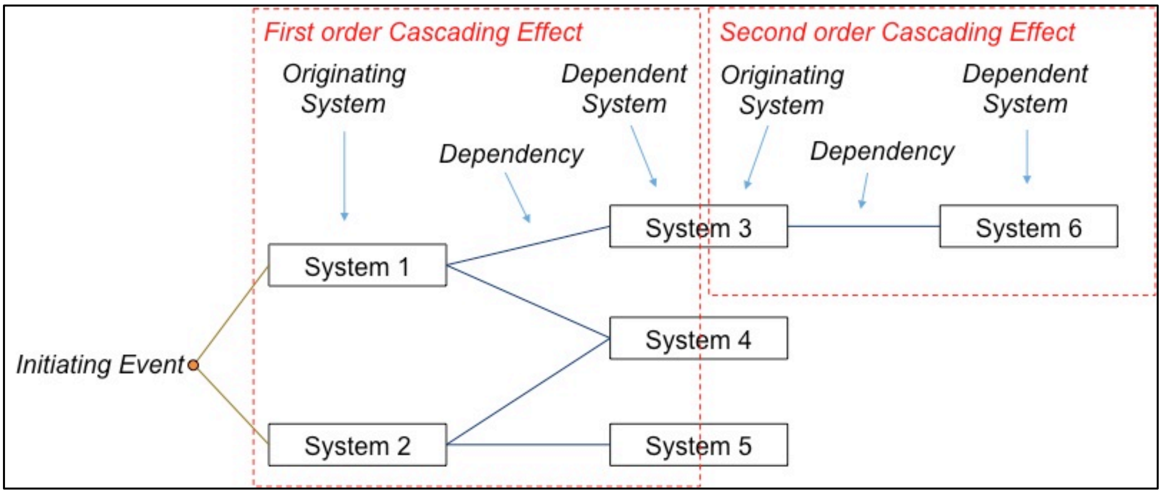


Figure 2. Illustration of terminology.

4.2 System definitions

The definition of cascading effects used in this paper mentions systems, but leaves the meaning of a system up for interpretation. In fact, systems are an essential part of the definition. Determining what a system is, and its boundaries, is important but can always be criticised in one way or another since it is always possible to draw the boundaries differently. This is especially the case when dealing with larger, more complex systems. Cilliers (2001), for example, argues that the boundaries of a complex system can never be clearly defined, because:

> *"Boundaries are simultaneously a function of the activity of the system itself, and a product of the strategy of description involved. In other words, we frame the system by describing it in a certain way (for a certain reason), but we are constrained in where the frame can be drawn. The boundary of the system is therefore neither purely a function of our description, nor is it a purely natural thing." (Cilliers, 2001, p.141)*

Critical infrastructures can definitely be described, and often are, as complex systems (McDaniels et al., 2007; Peters, Buzna, & Helbing, 2008; Rinaldi et al., 2001). This leads to the problem mentioned above. In this thesis critical infrastructures will be treated as complex systems, and "system" will be the term dominantly used.

The difficulty of determining system boundaries can be demonstrated by comparing some classifications of critical infrastructures that has been used in Europe and U.S. lately.

In the United States, the critical infrastructures mentioned in official reports and directives have varied over time (1983-2003); ranging from 3 to 26 different systems (Moteff & Parfomak, 2004). Energy, Transportation, Telecommunications, Water Supply, Banking and Finance, Emergency Services and Government Continuity are the ones mentioned most frequently in the U.S. reports. The sectors used by the two most recent reports in the article are presented in Figure 3.

The Swedish Civil Contingency Agency (MSB) uses 11 sectors of important societal activities (i.e. critical infrastructures), with some further division into functions within each sector (Gellerbring et al., 2014).

A research group from the Netherlands divides critical infrastructure into 12 groups, similar to the MSB ones (Luiijf et al., 2009).

For the purpose of the CascEff project, 21 different systems are used. This classification provides a bit more detail within the two major sectors energy and transportation as well as some additional systems important for the project. The systems have been chosen to capture cascading effect on a societal level. They have also been defined more according to the infrastructure they use, for example the different transportation systems all use different infrastructure, even if the purpose is generally the same: to carry goods and people.

The four different classifications are shown in Figure 3, where the different classes have been ordered by similarity. Noticeable is that only a few of the system classes are unique to their classification, which, albeit the sample is small, gives an indication of agreement among the research community.

Figure 3 also demonstrates that, even though the CascEff classification contains more systems, it is within reasonable agreement with the previous research in the area of critical infrastructure.

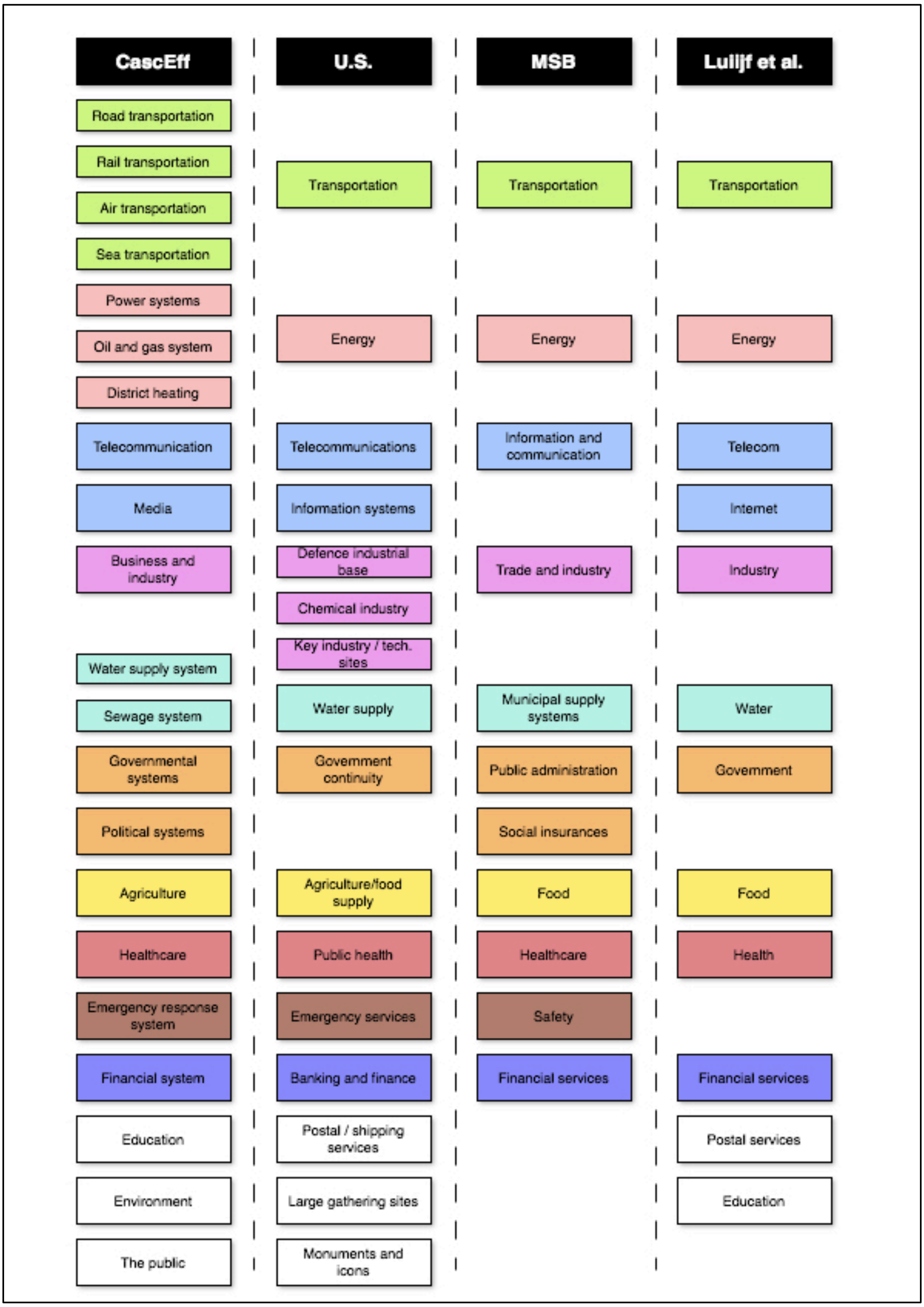


Figure 3. Comparison of system boundaries between CascEff, U.S. reports and executive orders (Moteff & Parfomak, 2004), Swedish Civil Contingency Agency (MSB) (Gellerbring et al., 2014) and a Dutch research group (Luiijf et al., 2009).

4.3 Desired characteristics of cascading effects

One could include as many characteristics of cascading effects as one need, but it will also make the information gathering process more demanding. There are, however, some that has been deemed to be essential or more interesting for this thesis. These include the originating system, the dependent system, type of dependency, consequences on the dependent system, time start and end, spatial extent, cascade order and conditions. Why these are deemed important will be discussed in each of the following sections describing the aspects.

Since these characteristics are deemed extra important, it should be a requirement for the suggested method to be able to gather information about them. Therefore, they will also be used to evaluate existing investigation methods in Chapter 5.

Before presenting the suggested characteristics in more detail, it should be noted that the initiating event is not considered a characteristic of a cascading effect within this thesis. Instead it is used for informational purposes and to find the direct effects of the event. This is due to the definition of cascading effects used in this thesis, where the effect has to propagate from one system to another. While some could argue that an initiating event can be a system, e.g. weather system, it is harder to argue that a fire or a train derailment is a system of its own; therefore it is treated as a trigger instead.

4.3.1 Originating system

An originating system is defined as a system in which a failure propagates to another system. For example a storm (initiating event) that strikes a power system (originating system), which leads to propagation of effects to other systems.

4.3.2 Dependent system

A dependent system is defined as a system, which is affected by a failure in another system. For example a failure occurs in a power system (originating system), which affects a telecommunication system (dependent system).

The most basic information needed regarding cascading effects is to know which systems are affected, here represented as the *originating system* and the *dependent* *system*. With this information, supported by enough data, it should be possible to determine which systems are more likely to affect other systems.

4.3.3 Type of dependency

Systems can be dependent in different ways: physical, cyber, geographical and logical (Rinaldi et al., 2001).

Physical dependencies exist when a system is dependent on another systems material output. A simple example is the road transportations' dependency on the petroleum industry; petrol, diesel and oil are required for the engines in cars and trucks.

Cyber dependencies are similar to their physical counterpart and occur when a system is dependent on information from another system. For example, the safe operation of railway transport is dependent on accurate information about the trains' positions and speed, railroad switches, etc., which is provided by a specialised information system.

Since both physical and cyber dependencies means that one system is dependent on the function of another, they can also be referred to as *functional* dependencies.

If two systems can be affected by the same local event, they are *geographically* dependent. A quite common example is to use the same tunnels or pipes for the power grid and telecom cables (because it is cost efficient), but a small fire in a tunnel would affect both systems.

The fourth kind of dependency, the *logical*, is in essence the cases that do not fit into the other types. It is often the result of human behaviour and decisions, an example is holidaymakers flocking to highways due to low petrol prices, causing traffic congestions, thus, again, linking the petroleum industry to road transport, but in a different way (Rinaldi et al., 2001).

In order to break the propagation of effects, one must know what kind of mechanism that is enabling the propagation, the *type of dependency*. Knowing the type of dependency can help the incident strategic command decide which strategy is most suitable. If the dependency is logical, for example people calling their relatives after a disaster and blocking emergency calls, information to the public, asking them to restrict phone calls to emergency only, might be the best approach. On the other hand, if it is a functional dependency affecting the same system, for example a power failure disabling mobile phone towers, the strategy might be to make sure repair crews can get to the affected areas safely.

4.3.4 Consequences – Dependent system

The consequences of a failure in the dependent system, which can be further distinguished into internal, affecting system only, and external, affecting society. Using the same example as in dependent system: the consequences in the telecommunication system might be non-operational mobile phone towers (internal consequence) and a number of people or organisations without any phone service (external consequence).

Learning more about the *consequences* of cascading effects is of interest when it comes to prioritisation, for governance and first response alike. Greater consequences usually require more immediate attention, whereas lesser ones could be ignored, if needed. However there is a great deal of uncertainty involved, since there always are conditions affecting the consequences: a power outage during summer in Sweden might be quite unproblematic, but the same outage can be of serious concern during winter.

4.3.5 Time start and end

The starting time, when the dependent system is starting to get affected, and ending time, when the dependent system is restored to normal operations, of a cascading effect can be used to determine the duration of the effect as well as the speed of propagation.

The *time start* and *time end* characteristics are also useful for planning an effective response. The time-lagged effects are of particular interest, since they might be preventable or at least mitigable. It is for example reasonable to prioritise systems that propagate effects faster over systems that have a slower development. The time start and end will also give a more detailed picture of the event-chain and make it easier to map the effects in the right order.

4.3.6 Spatial extent

The spatial extent refers to the area that is affected by the cascading effect. Many countries divide their response efforts in local, regional, national and international levels, which is one way to map the spatial extent. Another could be to use geographical information systems or GPS coordinates.

Spatial extent can also be used to inform response decisions, cascading effects with a large extent are usually more demanding to handle and is thus more desirable to prevent, if possible.

4.3.7 Cascade order

The order of the pair of systems in an event, the first pair being the first order and if the effect should propagate further, the next pair would be the second order etc. See Figure 2 for an illustration.

The *cascade order* can for example, together with originating system, be used to identify which systems that are more likely to propagate effects (i.e. the originating system of the first order). Securing the functionality of these systems at an early stage will likely reduce the amount of cascading effects.

4.3.8 Conditions

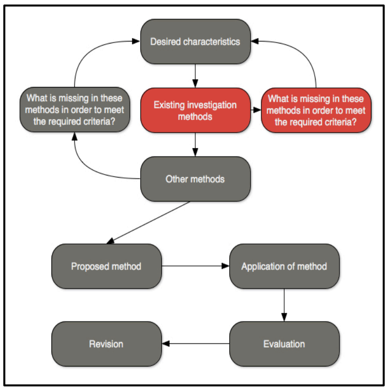
There will always be circumstances that affect cascading effects, either mitigating or aggravating the probability of a cascade or the consequences of the same, for example if bad weather keeps people inside their houses during a toxic gas leak, thus mitigating the exposure. The term for these circumstances will in this thesis be called *conditions*. These conditions are interesting to study, since they can be used to prevent or mitigate cascading effects. Conditions that mitigate the effect are desirable to recreate during another event (if possible) and likewise the conditions that aggravate the effects are desirable to avoid (again if possible).

To characterise conditions is not an easy task, since they come in every shape there is and in many cases they can be beneficial to some systems and, at the same time, have a severe effect on others. Another aspect to consider is that many conditions are case or system specific, for example London's Air Ambulance had a gathering a few hundred meters from the initial explosion during the London bombings in 2005, allowing them to assemble 27 highly specialised physicians and paramedics instead of the normal two-man team (Hallet, 2011). The problem with the system specific conditions is that they are not applicable when the particular system is not involved.

There are, however, some types of conditions that are more general in nature. For example, consider the time of the day or year, *timing*, and how it could affect a power outage. In winter with cold weather, people who depend on electricity for heating are more vulnerable than in the summertime, while the same outage might cause problems with cooling in summers, making other groups vulnerable, especially sick people. It is reasonable that the timing will affect the results of almost any kind of cascading effect.

Other general condition types, that are easily identifiable, are *weather conditions* and the *type of location* where the event take place or where the cascading effects take place. There might be other general types as well; perhaps a case study will bring light to some of them.

5 Existing incident investigation methods



In this chapter, a review of several different incident investigation methods developed and used by different organisations is presented. The review will be used to provide input for the development of the method for studying cascading effects. The methods are first described shortly, then an evaluation based on the perceived ability to gather information about the desired characteristics is summarised in a table, followed by a discussion. For more detailed descriptions, see the references related to each method.

The review was conducted with the help of other reviews: Sklet (2004) and Katsakiori et al. (2009). Most of the methods mentioned in these articles were researched individually as well, using the original creators works whenever possible. This was complemented by related articles found in scientific databases such as Scopus and Google Scholar as well as literature from Lund University libraries.

5.1 Events and causal factor charting and analysis (ECFC/A)

The ECFC/A method is developed by the U.S. Department of Energy (DOE) and is the basis of the investigations conducted by the department (DOE, 2012). The charting is conducted throughout the whole investigation process, continuously updating a timeline of events on the x-axis (from left to right), with their respective causal factors (i.e. conditions) on the y-axis. The analysis uses deductive reasoning in order to determine which events and causal factors that actually contributed to the accident, removing the ones that did not. The aim is to map all the contributing events up until the accident.

Barrier analysis, change analysis and root cause analysis are also vital parts of the DOE investigation process, used as support to the charting of events (DOE, 2012).

5.2 Barrier Analysis

The foundation of the barrier analysis is Haddon's energy model. The main principle is that an excess of energy from a hazard which a target then absorbs causes an accident (Haddon, 1980; Kjellén, 2000). Barriers are means to control, prevent or impede the energy from reaching the target (Sklet, 2004).

The basic steps according to the DOE manual are (DOE, 2012):

- Identify the hazard and the target.
- Identify each barrier.
- Identify how the barrier performed.
- Identify and consider probable causes of the barrier failure.
- Evaluate the consequences of the failure in the accident.

The barrier analysis is incorporated in many accident investigation methods, such as the MORT, TRIPOD, MTO-analysis and the AEB presented later.

A problem with barrier analysis in this context is the very narrow perspective; the hazards and respective barrier(s) are studied one at a time with no regard to timeline. However, one could view the originating system as a hazard, the dependent system as the target and then try to find barriers that will stop the propagating effects. To successfully apply this perspective, the kinds of energy that is usually considered most likely have to be adapted. This also questions the usefulness of the well-established prevention strategies that have been developed with this model, should it be used to study cascading effects (Haddon, 1980).

5.3 Change Analysis

The principle of change analysis is to compare the accident timeline with some kind of baseline when the system was operating under normal conditions, for example the week before or according to the design. The differences are analysed to determine what kind of impact they have on the outcome. This of course requires some kind of mapping of events before it can be conducted. In the DOE framework it is used to identify additional causal factors after a preliminary ECFC has been done (DOE, 2012).

5.4 Root Cause Analysis (RCA)

A root cause analysis aims to identify fundamental deficiencies in safety management systems that affects several causal factors and which would prevent similar accidents if corrected (DOE, 2012). There is no real agreement on what a root cause is amongst practitioners (Sutton, 2008) and performing an analysis forces the investigator to use their own judgements (DOE, 2012). Again, this requires some kind of charting and analysis of events before a root cause analysis can be performed.

5.5 Event Tree Analysis (ETA)

The event tree analysis is mainly used as a risk assessment method, where the focus is on event sequences after an initiating event (Kjellén, 2000). An event sequence is affected by whether safety functions and barriers are successful or not (Sklet, 2004). According to Sklet it can also be used as an investigation method, through the identification and illustration of the accident path.

The method has some similarities to CascEff's way of charting cascading effects (i.e. start with an event and map a sequence of events (cascading effects) that follows it), but takes little consideration to conditions.

5.6 Acci-map

Like the ETA, the Acci-map is not a pure investigation method, but offers an interesting perspective (Sklet, 2004). It was developed by Rasmussen and the Swedish Rescue Services Agency and utilises an organisational perspective where the focus is on six levels of decision-making, from equipment and staff to regulatory and governmental level (Rasmussen & Svedung, 2000). The accident is mapped from left to right according to the levels, where arrows are used to indicate influences.

5.7 MTO-analysis

The MTO-analysis, developed for the Swedish nuclear industry, is based on the idea that human, technical and organisational factors should be regarded as equal and interlocking parts of system safety (Rollenhagen, 2003). This is done by a structured analysis with event-cause-diagrams, a change analysis and a barrier analysis, complemented by a checklist for common failure causes (Sklet, 2004). The diagram is drawn with the event chain in the middle, from left to right. The various conditions are plotted above, with a change analysis in the top. Below the event chain, the barrier analysis is presented.

5.8 TRIPOD

Accidents occur when active failures and latent conditions causes holes in the barriers protecting the systems, allowing the hazards to penetrate the defences and do damage (Reason, 1997). Furthermore, these active failures (i.e. errors or unsafe acts performed by workers) are a result of latent conditions (e.g. design flaws, working procedures and maintenance failures), which are the effect of decisions made by governments, designers, organisation management and more. An investigation should start with the accident and work backwards to identify these latent conditions (Sklet, 2004).

5.9 Accident Evaluation and Barrier Function (AEB)

AEB models an accident as a sequence of interactions between technical and human systems; to stop the accident from reoccurring the sequence must be broken through an adequate barrier (Katsakiori et al., 2009; Svensson, 2000). This method focuses only on one chain and does not account for time. AEB does not try to find underlying causes, because the aim is to analyse why barrier functions failed and how to strengthen them (Katsakiori et al., 2009).

5.10 Sequential Timed Events Plotting (STEP)

STEP is more of a way to visualise an accident than an analytical tool, the main feature is the use of a multi-linear event chain (Favarò, Jackson, Saleh, & Mavris, 2013; Sklet, 2004). In Favarò et al. (2013) they use the technique to investigate air flight incidents.

Agents, persons or objects involved in the accident and that can change states or interact to create events, are plotted on the y-axis of the diagram (Nano & Derudi, 2013). Further, the x-axis represents time and arrows leading from and to events represent the sequential order as well as dependencies. Events are plotted on the row of the agent it belongs to and at the time it took place.

5.11 Systemic Cause Analysis Tree (SCAT)

SCAT is based on the ILCI accident model, which consists of five blocks, each representing a part of an accident (Katsakiori et al., 2009; Sklet, 2004). The five blocks in the model are: Lack of control (management level), Basic causes (job and personal factors), Immediate causes (substandard acts and conditions), Incident (contact with harmful energy/substances) and Loss (Kjellén, 2000). An accident is investigated in the reverse order, with supporting checklists in order to encourage an investigation that stretches deeper than operator error (Sklet, 2004).

5.12 Management Oversight and Risk Tree (MORT)

The MORT method makes use of the Haddon's energy model, thus defines an accident as a lack of or inadequate barriers or control functions (Katsakiori et al., 2009; Kjellén, 2000). MORT provides the analyst with a logical tree divided into three main branches, the S, R and M, each with a comprehensive set of questions (Katsakiori et al., 2009). The S-branch deals with oversight and omissions specific to the accident, the R-branch is known risk factors, but for some reason not controlled, and the M-branch investigates the management system (NRI, 2009). Before working with the questions in the tree, some kind of event sequencing (e.g. ECFA) and a barrier analysis should be performed (NRI, 2009).

A problem with MORT is that it requires a lot of resources and expertise and is best suited for big, bureaucratic organisations, such as the U.S. nuclear industry, where it is used (Katsakiori et al., 2009).

5.13 Fault Tree Analysis (FTA)

In a FTA, the analyst choses and defines an undesired event. All possible contributing events and factors are then diagrammed in a logical tree structure, using logical AND/OR gates to display relations between events (Katsakiori et al., 2009). The FTA gives little support to the investigating analyst, but a tool to visualise a logical representation of the accident (Katsakiori et al., 2009; Kjellén, 2000).

5.14 Influence Diagram

Paté-Cornell used an influence diagram as the basis of an investigation of the Piper Alpha accident, with a particular focus on three levels: basic events, decisions and actions and organisational (Pate-Cornell, 1993; Sklet, 2004). In order to draw a proper diagram, the basic events must be studied, and all actions and decisions related to that event are also mapped. Lastly, the actions and decisions are checked to see if they can be the cause of basic organisational factors (Sklet, 2004). The influence diagram should make a distinction between the different levels and show how each event, decision or organisational factors are related to each other, usually by boxes and arrows (Pate-Cornell, 1993).

5.15 Summary

Typically, the investigation methods can be divided into three aspects: to gather information, to structure information and to analyse information. This said, not all methods cover all three aspects.

The way the investigation methods use to *gather* information about the event include interviews, workshops, physical evidence gathering, checklists, schematics, on site inspections and more. Some methods do not provide any support for gathering data, thus are purely analytical (e.g. RCA, AEB, FTA). Interviews are mentioned or implied in many methods, for example the use of checklist usually involves talking to people in order to answer the questions in the list. The more comprehensive methods like MORT, STEP, TRIPOD, ECFC, Acci-mapping all requires interviewing persons involved.

The most common form of *structuring* the information gathered is some form of diagram, logical tree or a table.

The largest difference shows when it comes to *analysing* the information, where most methods use their own accident model or a variance of one. The principles of the energy-barrier model (Haddon, 1980) is trendsetting in models such as AEB, MORT, Barrier analysis, MTO-analysis and ETA.

What all these methods have in common is that they focus on the events leading up to the accident or incident (i.e. the initiating event), which means little attention is paid to the aftermath. This poses a problem for researchers interested in cascading effects, because they take place after the initiating event.

A secondary problem, and also related to the first, is that many methods use a narrow system perspective. They either focus on a single event chain (AEB, FTA), or in other cases also organisational conditions are taken into consideration (MORT, MTO-analysis, SCAT) and some stretches even further to governmental level (Acci-map, TRIPOD, influence diagram, STEP), but they are still usually confined to a single company, system or sector. This might be due to the background of which most of these methods have emerged; many were developed to handle occupational hazards (e.g. SCAT, TRIPOD, MTO-analysis) or to investigate accidents within certain sectors (e.g. AEB, MORT for nuclear industry, ECFC for the U.S. Department of energy, FTA for the U.S. Department of Defence).

The effects on society are not mentioned explicitly in any of the studied methods and this is the level, which the method developed in this thesis is interested in. However, most of the studied investigation methods do recognise that the chain of event of an accident is affected by conditions.

Figure 4 presented below shows a comparison of the methods presented in this chapter. The mapping is made with respect to how well the author believes the different methods would provide information about the desired characteristics if they were to be used while focusing on cascading effects. It is based on the description of the methods found in the references noted in the right column. Thus, the methods have not been applied on an actual case.

From the figure one can draw the conclusion that some methods seem less useful in this context, for example MORT and Change analysis. Others are more promising, like the STEP-diagram, Acci-map or ECFC/A. There are, however, some problems with using any of the accident investigation methods as a cascading effects investigation method, since none seems capable of covering all the required characteristics.

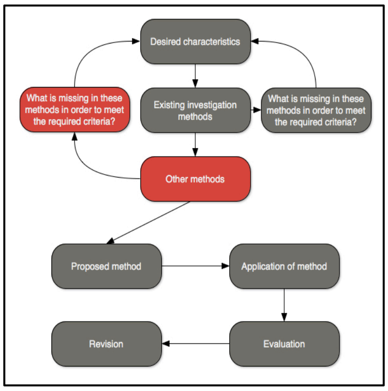
From the way these methods gather information, the interview or workshops seems like the most feasible options. Physical evidence gathering is an option privileged to authorities. Schematics could potentially provide a better insight to why a cascading effect occurred, but only the parts it describes. However, the schematics usually describe systems on a much lower system level than desired in this thesis. A checklist of questions that are adapted to all kinds of events would probably become too extensive.

The methods uses several different ways to structure information, but the ones that displays it the most clearly are the visual representations such as diagrams or flowcharts. Tables quickly become hard to overview and it is hard to represent dependencies in a practical way. The influence diagram, the STEP diagram and the Acci-map all displays information in a way that makes it easy to get a quick idea of what has happened, they also are able to represent dependencies, usually by lines or arrows.

Method	Dependent System	Originating system	Dependency Type	Consequences	Time Start	Time End	Spatial Extent	Conditions	References
ECFC/A	Yes	Yes	Maybe	Partially	Yes	Yes	Maybe	Yes	DOE (2012), Sklet (2004)
Barrier analysis	Yes	Yes	Yes	Partially	No	No	Maybe	Maybe	DOE (2012), Haddon (1980), Kjellén (2000),Sklet (2004)
Change analysis	No	No	Maybe	No	No	No	No	Yes	DOE (2012), Sklet (2004)
TRIPOD	Yes	Yes	Maybe	Maybe	Maybe	Yes	Maybe	Yes	Reason (1997), Sklet (2004)
RCA	Yes	Maybe	Maybe	No	No	Yes	No	Yes	DOE (2012), Sklet (2004), Sutton (2008)
FTA	Yes	Maybe	Maybe	No	Maybe	Yes	No	Maybe	DOE (2012), Katsakiori et al. (2009), Kjellén (2000), Sklet (2004)
Influence diagram	Maybe	Maybe	Maybe	Yes	Yes	Yes	Maybe	Maybe	Paté-Cornell (1993), Sklet (2004)
ETA	Yes	Yes	Maybe	Partially	Yes	Yes	No	No	Kjellén (2000), Sklet (2004)
MORT	Yes	Yes	Maybe	No	No	No	No	Maybe	Katsakiori et al. (2009), Kjellén (2000), NRI (2009)
SCAT	Yes	Maybe	No	Partially	Yes	Maybe	Maybe	Maybe	Katsakiori et al. (2009), Kjellén (2000), Sklet (2004)
STEP	Yes	Yes	Maybe	Maybe	Yes	Yes	Maybe	Maybe	Favarò et al. (2013), Nano & Derudi (2013), Sklet (2004)
MTO-analysis	Yes	Yes	Maybe	Maybe	Maybe	Maybe	Maybe	Yes	Rollenhagen (2003), Sklet (2004)
Acci-map	Yes	Yes	Maybe	Maybe	Yes	Yes	Maybe	Yes	Rasmussen & Svedung (2000), Sklet (2004)
AEB	Yes	Yes	Partially	Maybe	Maybe	Yes	No	Maybe	Katsakiori et al. (2009), Sklet (2004), Svensson (2000)

Figure 4. Comparison of different investigation methods.

6 Other methods



To complement the literature study of incident investigation methods, a smaller study of other potential methods was conducted.

One article dealing with analysis and evaluation of emergency response was particularly interesting (Abrahamsson, Hassel, & Tehler, 2010). The article includes a technique called counterfactual reasoning, which is used to create scenarios for evaluating a response. The technique was studied additionally and is presented in section 6.1.

6.1 Counterfactual reasoning

Counterfactual thinking is something most people do; most of us have had thoughts of the following kind: “If I had done this instead of that, then this would have happened instead”. A counterfactual thought is often defined as *“mental representations that are explicitly contrary to facts or beliefs”* and do more often than not formulated as conditional statements (Roese & Morrison, 2009, p.16). These statements are usually divided into an antecedent (“If I had done this”) and a consequent (“then this would have happened”).

Counterfactual reasoning is closely related, but is an analytical method, which constructs alternate scenarios using counterfactual events, usually in order to provide input to decision making. It can be used both retrospectively, thus changing historical facts or add new ones, or prospectively, making an assessment of the future.

According to (Hendrickson, 2008), all counterfactual reasoning should start with creating an antecedent scenario, which he describes as a precisely formulated series of events that makes the antecedent true. Using the example “If the green party wins the election, the coal power plants would be forced to close”, an antecedent scenario consists of all the events and circumstances leading up to the green party winning the election (such as a skilled party leader, effective campaigning or a political scandal amongst competitors). The general principles when choosing an antecedent scenario is to choose the one that preserves history best (in the case of retrospective reasoning), have the highest probability and has the fewest amount of deviations from reality (Hendrickson, 2012).

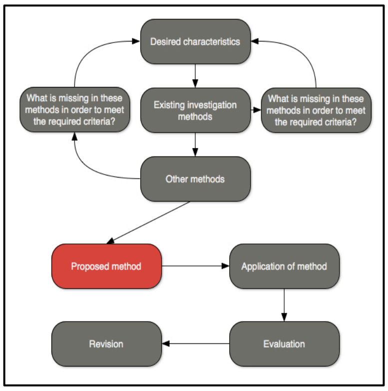
Hendrickson further explains the next step, which is to create the intermediate scenario, the series of event from the antecedent being true until the consequent scenario, as well as the likelihood of the events (Hendrickson, 2008). In the example above, from the election being won until the plants are forced to close (this could include events like propositions in parliament, increased taxes on carbon emissions etc.).

The final step is the consequent scenario, where the consequence and the aftermath of it are described. Here basically every nonzero probability scenario, which is not in contradiction to previously described events, is allowed, but they should also be of strategic importance for the purpose of the analysis (Hendrickson, 2008).

Hendrickson's guide to counterfactual reasoning is very rigorous and designed primarily for the intelligence community, where it is used as a supporting tool for making strategic decisions, which may have huge consequences (Hendrickson, 2008). The trade off is the time required to make such detailed scenarios, a reasonable trade for an organisation with a lot of resources and the need of the best possible assessments.

Counterfactual reasoning is not primarily a method for information gathering. However, if questions that encourage counterfactual reasoning are asked during an interview or a workshop they could give more information about conditions from the interviewees. Conditions are related to counterfactual reasoning, since conditions often are out of the ordinary and thus easily triggers counterfactual thoughts. As an example, a person that usually keeps batteries for emergency flashlights at home. But this day, when there is a power failure, there are none to be found, which can be labelled as an aggravating condition according to the definition. The first thought that comes to mind is probably "if only I had had batteries at home, then I could see what I am doing", which is counterfactual thinking. If taken one step further, the interviewees might have thought of such conditions and also the effects of such a conditions, thus a potential cascading effect. These potential cascading effects could serve as a compliment to the actual documented effects.

7 Method for investigating cascading effects



As can be seen in Figure 3 none of the incident investigation methods meet the requirements that has been set up earlier. This is not surprising since the methods do not ask the same question as is done in this thesis. In order to investigate cascading effects, there is a need to shift focus from "What caused the accident?" to "What did the accident cause?" and accompanying follow-up questions. In this chapter a method for investigating cascading effects will be proposed, it will be divided into two parts: gathering information and structuring information, which will then be shortly summarised in a diagram. The next chapter will apply the method in a case study.

7.1 Gathering information

For information gathering, a semi-structured interview with key persons within the systems is the proposed technique, even though workshops would probably work as well. The workshops, however, requires representatives from many organisations to be present at the same time, making it hard to schedule. It is also questionable if they are as willing to share their experiences in a big group, compared to an interview.

Semi-structured interviews are useful for gathering information when the information one needs is not clearly defined or are not obvious to the respondent. They allow for explaining of terms and are also flexible enough to be adapted during the interview, so that an opportunity to gather vital information about the system is not lost. Interviews are used by several incident investigation methods as well.

However, to be able to perform any interviews, one must identify at least one affected system, preferably more. An ideal situation is if there is an existing study, the different actors mentioned in the study can then be used to conduct the first series of interviews. Alternatively or additionally, media articles can be used to provide an idea of what systems are involved, for example if a spokesperson from an agency is mentioned in an article, their organisation is probably involved in some way. Following this identification of a first point of contact, snowballing is usually possible as is shown in Figure 5.

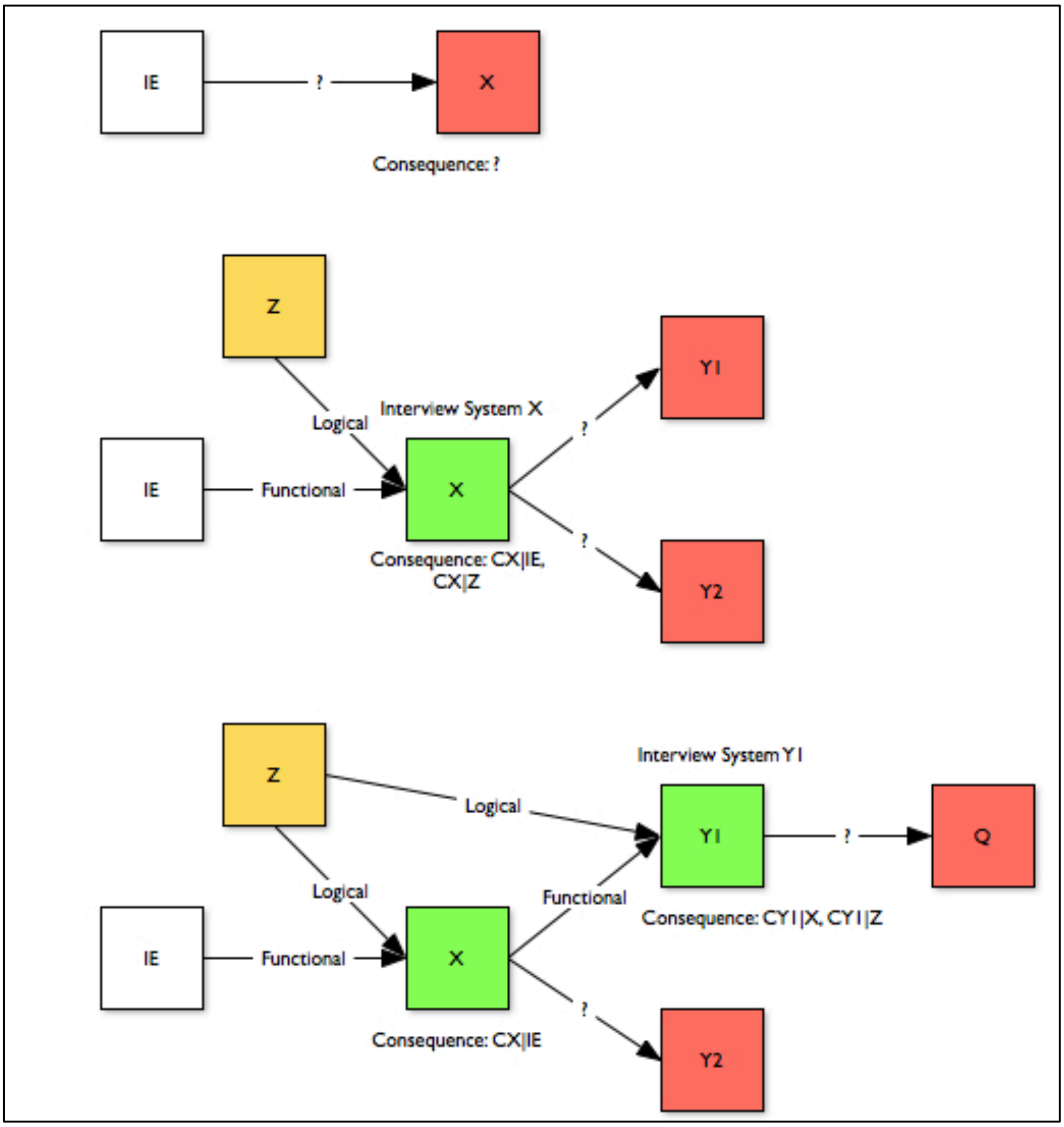


Figure 5. The figure shows the interview snowballing in theory. The top part is the starting point, when little or nothing is known. The middle part shows what is known after the first interview, the green square represents an interviewed system (X), the yellow square (Z) is a previously not known system that affected X and the red squares (Y) represents systems that are dependent on X. The bottom part shows an example after the Y1 system has been interviewed, with new information.

The goal is to identify dependency-pairs, two systems that are connected to each other via a dependency, and conditions associated with the pairs. The interviews should focus on the core information needed, with some room for improvisation if something of interest is mentioned, that is not covered by the interview support. The following subjects should be explored during the interview:

- Dependencies from other systems
- Dependencies to other systems
- Consequences of dependencies: what kind, timespan, spatial extent
- Mitigating or aggravating conditions

Additional affected systems should emerge during the interview process, which leads to new interviews and so forth. An illustration of the interview process is shown in Figure 5. The process can continue until no new systems are found or until the investigator is satisfied, for example when interviewing the remaining systems will highly unlikely provide any additional information due to the amount of second hand information about the system, depending on the purpose of the study.

To complement the more straightforward questions about dependencies and consequences, a few questions of counterfactual nature is added in the end. The purpose of these questions is to encourage respondents to think about fictional events; from there it is possible to ask *why* the event did *not* occur. This can depend on two things: either there is no dependency or there were some kind of condition that prevented the cascade, often the later. It is thus believed these questions will help revealing additional conditions.

7.2 Structuring information

To keep track of what is known and the relations between the systems, they should be structured in a working version of a diagram. Here, a variance of a STEP diagram is proposed. While there were other candidates, the STEP diagram required the least amount of adaptation. In STEP diagrams the different sectors are plotted on the same line in the y-axis and the cascade order on the x-axis, see Figure 6. The main difference from the original STEP diagram is the use of cascade order instead of time on the x-axis, it also focuses more on the consequences of the event, rather than the actions leading up to an accident. The type of dependency should be noted as well as short description of main consequences. An advantage of the diagram is that it displays a lot of information: the systems involved, the dependencies (and what type), the conditions involved with each system or cascading effect, the cascade order, which consequences each system suffered and from what system.

Each arrow represents a dependency-pair and the boxes show what system is affected and what the consequences are. If two originating systems affect the same dependent system, the consequences are divided by noting the originating system's number.

When the interviews are finished, the diagrams from each interview should be aggregated into one, representing the whole event. A suitable way of doing this is to start compiling all the direct effects from the event and insert them in the diagram, if there are any duplicates (they have been mentioned in two or more interviews) they should be removed. When all the direct effects are moved into the right position, the first order of cascading effects are copied into the diagram and again duplicates are removed. This proceeds until all effects from the interviews are in the final diagram.

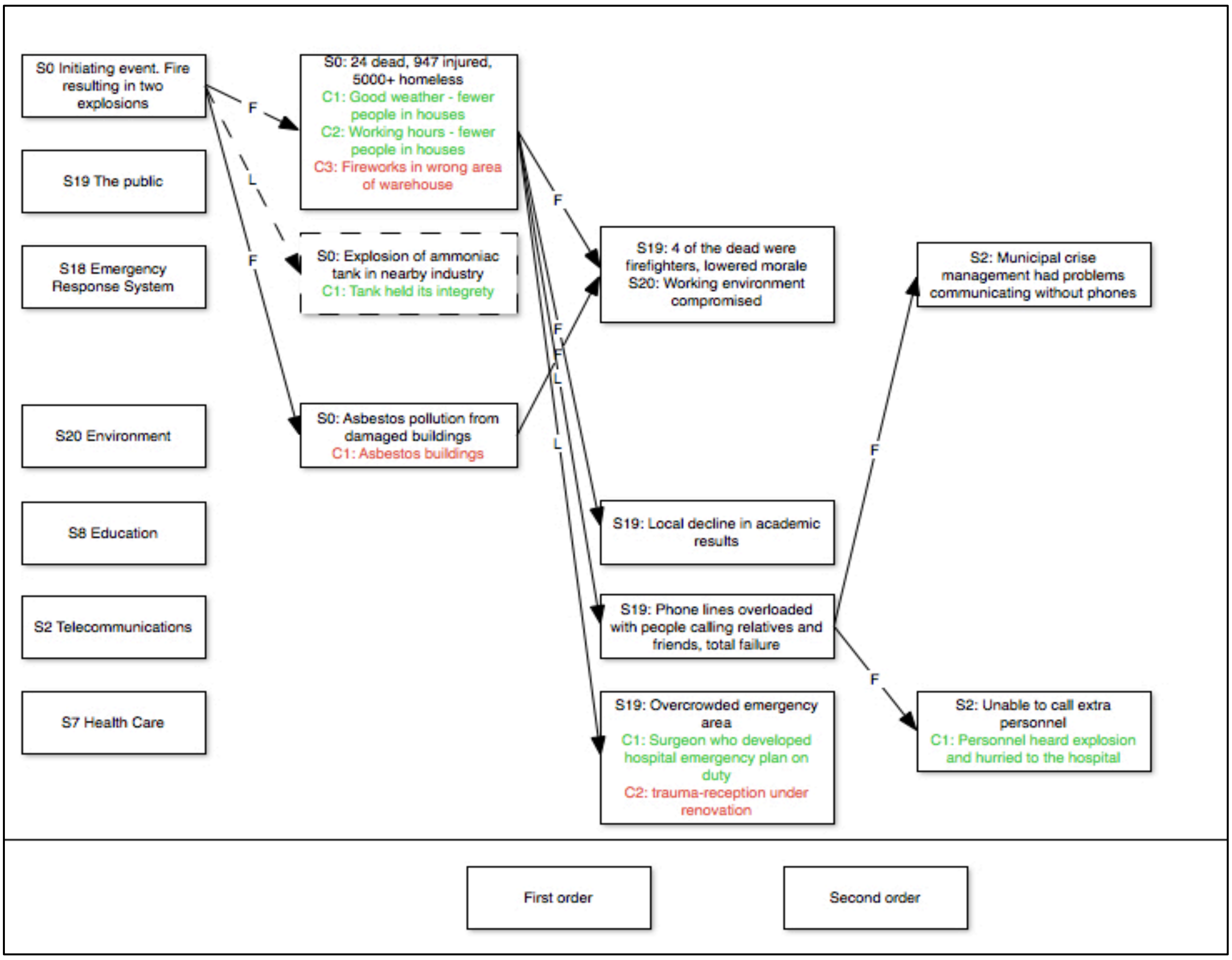


Figure 6. Example of working diagram, a variance of a STEP diagram, by the use of the case Enschede firework disaster (Socialstyrelsen, 2004; Webbink, 2008; Yanik, 2001). Dashed lines represent potential cascading effects and the green and red texts represent mitigating and aggravating conditions respectively. For more details of the incident, see Appendix D – Enschede firework disaster.

7.3 Summary

To provide a better overview of the method, Figure 7 displays the main parts as well as the intended order in which they should be executed. What is included in each part is described in more detail in the previous sections in this chapter.

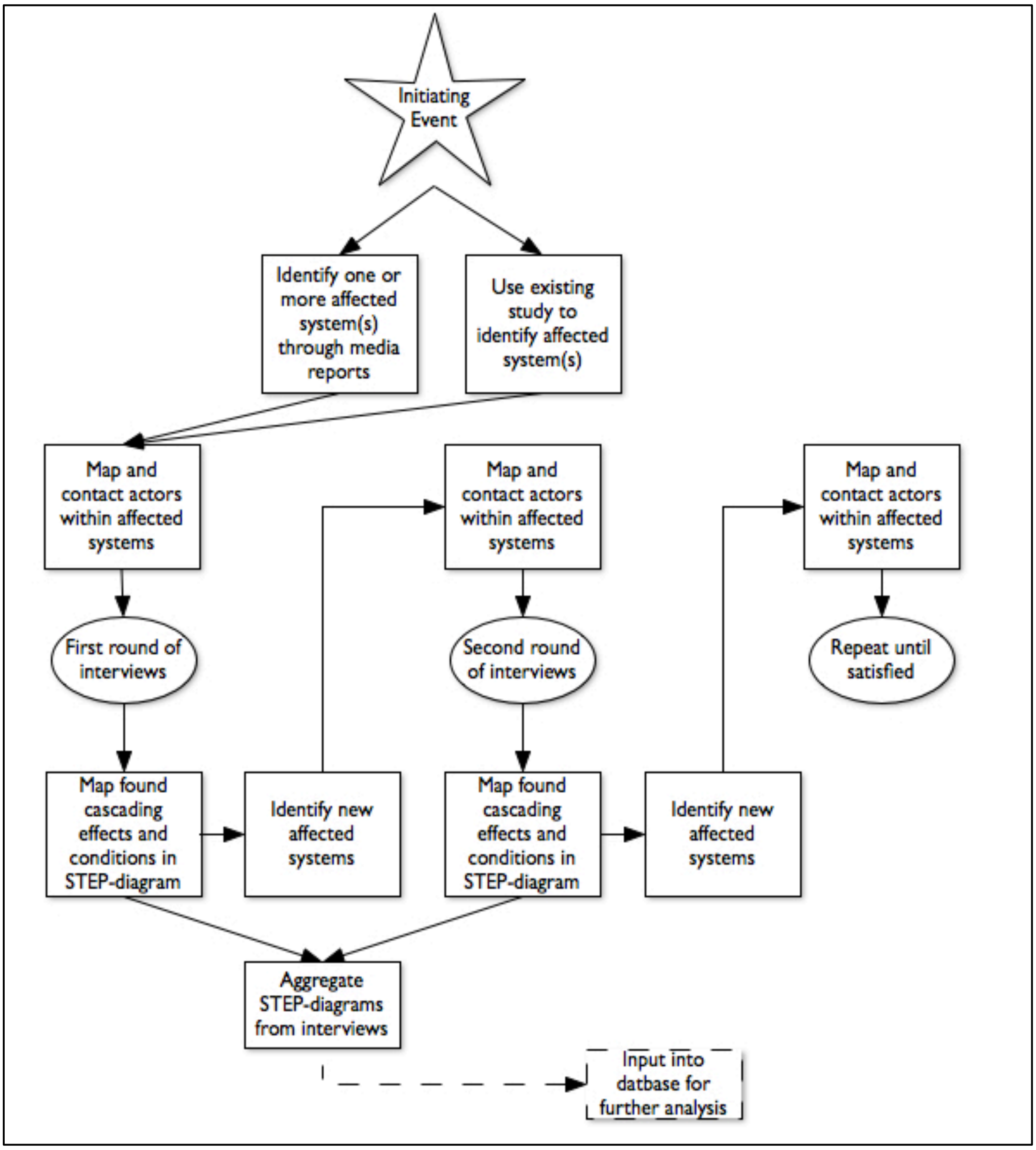
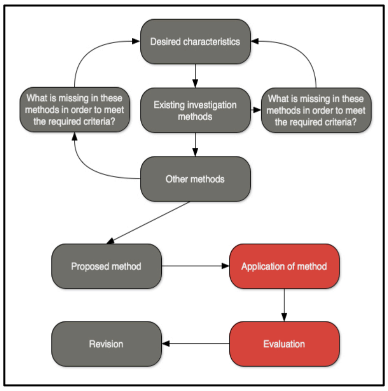


Figure 7. A principle flowchart of the whole interview process, from identification of affected systems until the finished STEP-diagram.

8 Application of method – Malmö flooding

In this chapter, a minor case study with the purpose of testing the proposed method will be presented. The main steps of the method are presented in Figure 7. First there will be a short introduction of the case, then a description of how the study was executed and lastly the results are presented.



8.1 Case introduction

On the 31st of August 2014, a Sunday, around 90 mm of rain fell over Malmö within 24 hours. It started early morning and a few hours later some organisations reported problems with flooding. The damages were many and at times the event was quite dramatic, with vehicles stuck in water masses, passengers still inside. The case was chosen because of the high potential for cascading effects, its manageable scale for a case study and for the convenience of a short travel distance.

8.2 Execution

At first media articles from several of the larger Swedish newspapers were examined to get a better understanding of the event and to identify organisations that might have had experienced the impacts of the flooding. Twelve organisations from different areas were identified and contacted, six of them agreed to an interview: RSYD (Rescue service), VA-SYD (Water and sanitation), Malmö Stad (Municipal government), Länsförsäkringar (Insurance company), Region Skåne (Health care) and Trafikverket (Road and rail transportation). All organisations have different responsibilities, but Malmö Stad has more of an umbrella responsibility. Other contacted organisations included the county police, emergency call centre, the county collective traffic, an electric power company, another insurance company and one of the bigger housing associations.

Representatives, with experience from the event, from each organisation were interviewed in Swedish. The interviews were conducted with some support (semi-structured), in the form of some written down questions and space for answers, see Appendix C – Interview support (blank). Answers were translated and transferred to a digital format and then mapped in a STEP diagram in accordance with the method presented in section 7.2. All information the respondents provided was mapped, no matter the size of the effects. Both cascading effects and potential cascading effects, thus "close calls", were mapped in the same diagram, but with a clear distinction.

During the interviews two of the questions specifically encouraged the respondents to engage in counterfactual reasoning:

> *Say the flooding happened during a Wednesday. Would the situation be better or worse for your organisation?*
>
> *What would have improved your organisations ability during the event?*

The first question was included because, from the newspapers, it seemed like the flooding caused a lot of problems with the traffic. How much traffic there is on the streets, depends a lot on how many people who have to get to work. Since that amount is a lot higher during weekdays than weekends, it was deemed interesting to see how it would affect the organisations.

The second question was deemed interesting since conditions that increases a systems ability to handle an event, could potentially be used to mitigate the cascading effects the next time a similar event takes place.

The questions could of course have been focused on other areas and it is possible to change these depending on the event that is being studied. It is important, however, that there are at least a few of these included in the interviews.

After the completion of all interviews, the mapped information was aggregated into a single STEP diagram to get an overview of the event as a whole. To do so, the different organisations answers have to be compared with each other. This meant that similar effects were sometimes clustered together and duplicates were removed.

8.3 Results

The interviews generated a total of 45 mapped effects and 32 conditions that affected 13 of the defined systems in section 4.3. Details can be found in Table 1.

Figure 8 and Figure 9 shows the aggregated STEP diagram (split up in parts for readability) from the case study. Since everything that the respondents deemed important enough to mention were mapped, the sizes of the consequences are very diverse; from organisations increased workload to flooded basements high-rise buildings to 68 patients being evacuated from the hospital (and potentially 300 more).

Table 1. A summary of results from case study, in numbers.

Effects (With Potential)	
Direct effects	11 (13)
First order effects	20 (24)
Second order effects	8 (8)
Total	38 (45)
Conditions	
Aggravating	15
Mitigating	17
Total	32
Dependency type	
Functional	36
Logical	9
Geographical	0
Total	45
Systems affected	
Total	13

As for the two last questions, the ones focusing more on counterfactual reasoning, it was possible to get the respondents to think in the way that was intended. To the first question, whether the situation would be better or worse if it occurred on a Wednesday, the answers were mixed. Three of the organisations thought the situation would be better for them, at least initially (Malmö Stad, Region Skåne, Länsförsäkringar), and for the same reason; it would be easier to call in extra personnel or resources on a normal working day. The other organisations thought they would be worse of, even though VA-SYD not so much, and the common reason is the increased traffic in the city, on roads in particular.

The answers to the last question, what could improve the organisations ability during the event, can be summarised into three things: improved cooperation between organisations, an early weather warning or better preparedness (in the form of pumps or predefined and trained groups of personnel).

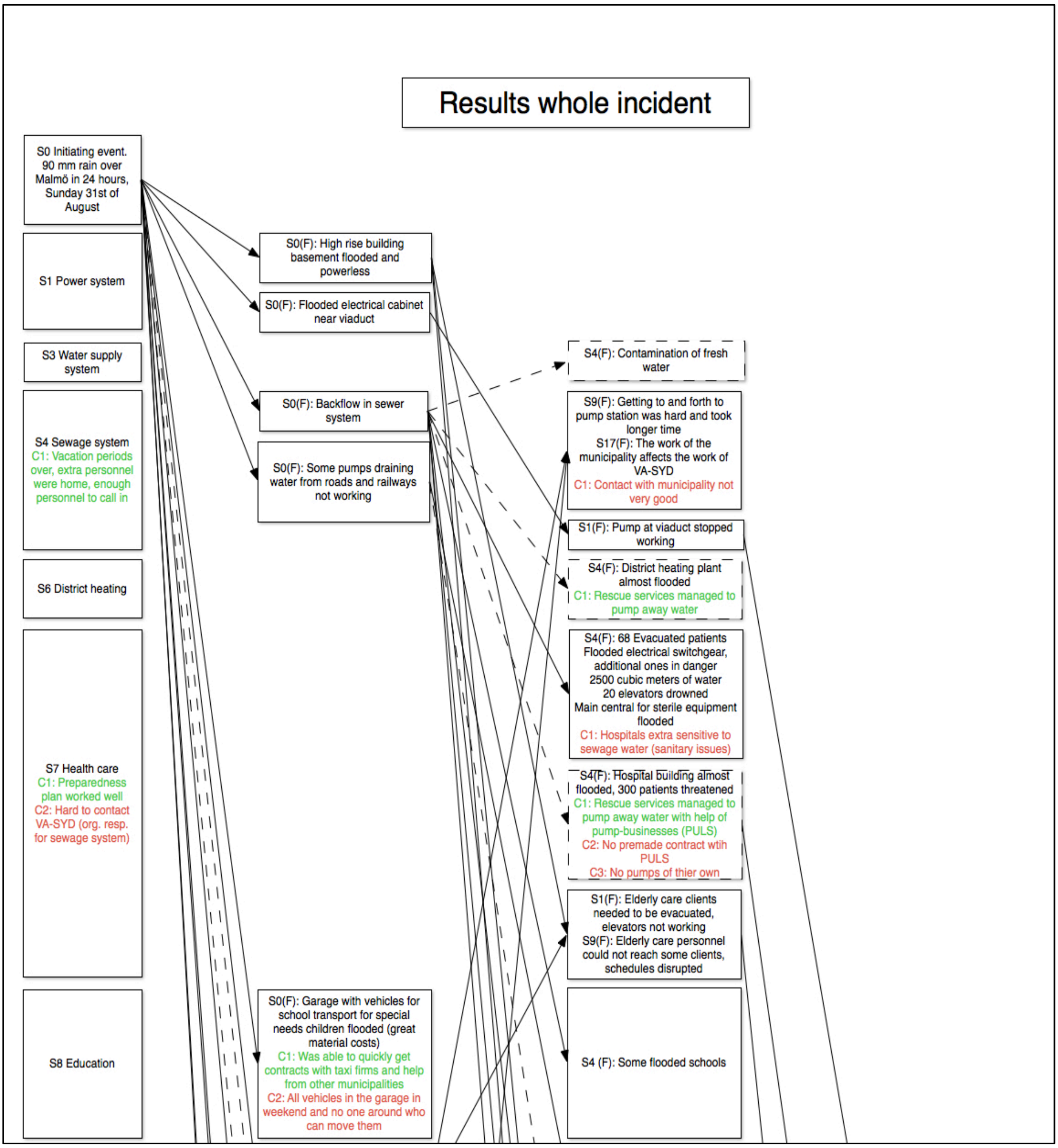


Figure 8. Part one of the case study STEP diagram. To the left are the systems, arrows indicate dependencies, boxes represents effects. In the boxes, first the originating system is mentioned by number, then the dependency type, the consequences and conditions. Green text represent mitigating conditions, whereas red text indicates aggravating conditions.

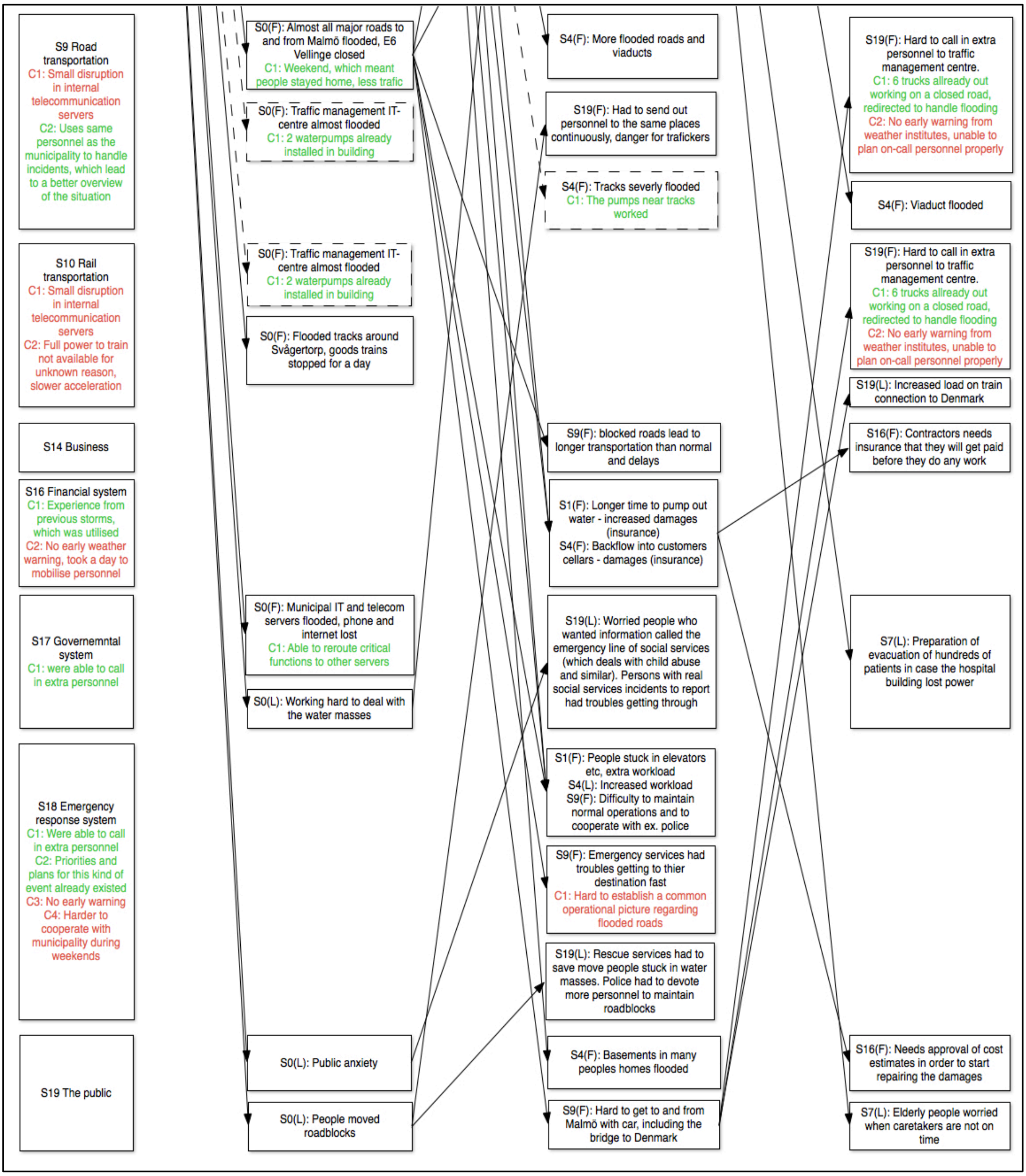


Figure 9. Part two of the case study STEP diagram. To the left are the systems, arrows indicate dependencies, boxes represents effects. In the boxes, first the originating system is mentioned by number, then the dependency type, the consequences and conditions. Green text represent mitigating conditions, whereas red text indicates aggravating conditions.

8.4 Method evaluation

The purpose of the method is to gather and structure information about cascading effects and present conditions in a useful and practical way, thus the first thing to be evaluated is its ability to gather the sought information. Then its ability to structure information is evaluated and lastly some general concerns and impressions are discussed.

8.4.1 Information gathering

In order to evaluate the proposed method, it is going to be compared the same way as the incident investigation methods. In Figure 4 the investigation methods were compared with regard to its estimated ability to identify: dependent system, originating system, dependency type, consequences, time start, time end, spatial extent and conditions. Later, other observations and experiences will be discussed.

From the results presented in Table 1 and in the STEP-diagram (Figure 8 and Figure 9) one can discern that the method is able to handle most of the criteria, dependent systems are there, as is originating systems, dependency types, consequences and conditions. However, time start, time end and spatial extent are not covered by the method as it is. Initially the intention was to cover these topics during the interviews, but it quickly became apparent that asking questions about time and extent regarding every cascading effect severely disrupts the flow of the interview. Constantly asking for details distracted the respondent from the main topic, cascading effects and related conditions, thus already during the first interview it was decided to skip this part.

There were times when the effects were very specified, like how many patients were evacuated, and other times they were very general, like the blocked roads. In order to quantify the cascading effects, it is necessary to ask precise questions, and repeatedly. As was the problem with time and spatial extent, these questions interrupted the flow of the interviews, however sometimes these questions were asked in spite of this.

Since all the effects brought up by the respondents were mapped, there is quite a high level of detail in the STEP-diagram, possibly too high level of detail. However, if one wants to restrict the number of cascading effects to the more important ones, it is quite simple to remove the effects that are deemed insignificant.

During the interviews, quite often the respondents would bring up so called "near misses", events that did not happen, but were stopped just in time, either by circumstances or intervention. These near misses were deemed interesting enough to map, even though not as a proper cascading effect, because should a similar situation arise with different conditions, the near misses have the potential to become cascading effects. It is also interesting to see what kind of conditions took part in stopping near misses from becoming a problem.

The interest from the organisations that participated in the study was quite high and sincere, out of twelve asked, six were able and willing to participate. All of them provided useful information, to greater or smaller extent, see Appendix A – Interview responses and Appendix B – Interview STEP diagrams for an overview.

How does this method compare to the more traditional one, i.e. studying post assessment reports and articles? In Appendix D – Enschede firework disaster a case from the Netherlands is presented, which has been mapped with the same framework as in this thesis, but with official reports and scientific articles as the only source of information. A comparison of the two events is shown in Table 2. By looking only in the table the result might seem clear, but bear in mind only two events have been compared. To come to any decisive conclusion, more events need to be studied with both methods.

Table 2. Comparison of the sources used and amount of information gathered between Malmö flooding and Enschede fireworks disaster

	Malmö flooding	Enschede firework disaster
Interviews	6	0
Written sources	0	3
Media sources	To identify suitable participants	0
Cascading effects (including direct effects)	45	9
Conditions	32	8
Systems affected	13	6

Using counterfactual reasoning as a method to gain some extra information about the event turned out to be quite natural and useful. The participants often engaged in counterfactual reasoning before they were introduced to the last questions in the interview support, see Appendix C – Interview support (blank). This is not very surprising, since it is something every human engage in every day.

8.4.2 Structuring information

The modified STEP diagram provides a good overview of an event and is quite easy to use, it does what it should do, give structure. It is not entirely unproblematic however. As can be seen in Figure 8 and Figure 9, the map can be quite large, which makes it difficult to present.

Sometimes it is hard to determine the level of detail in the effects, both which effects were relevant and to what detail the effects should be divided into. For example the flooding in a basement, which meant 68 patients had to evacuate, could be mapped as one effect in the health care system or as two, first the flooding in health care leading to a second effect on the public, the evacuation of patients.

The system categories presented in section 4.2 were useful and easy to use. Of course there were some ambiguities as to which system the cascading effects belong to, but using the principle of where it fits best, solved most of the problems. Asking for a second opinion can also help in deciding where to map the effect.

The aggregation of information from the different interviews is another area where the colours are grey. Even though there usually are clear connections between systems and effects during each separate interview, the whole picture is not that obvious. Determining what happened when and in what order has been hard to map, especially without time-data (or at least estimates).

Removing duplicates and such is a simple matter of comparison, and is noticed easily when compiling effects.

8.4.3 Other impressions

During the interviews, most of the conditions predicted in section 4.3.8 were brought up. Weather conditions naturally, since the event was a flooding. Also the timing aspect was important, in many situations essential equipment were a few minutes or an hour away from being flooded.

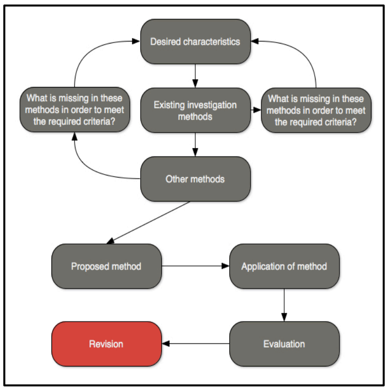
There were, however, other conditions that were mentioned often, such as the availability to call in extra personnel to handle the situation, thus the organisations ability to mobilize above normal capacity. Another cluster of conditions were related to communication between organisations, such as problems establishing a common operational picture amongst emergency response organisations.

The snowballing effect shown in Figure 5 was not very apparent, however the 6 interviews provided first-hand information from 8 different systems (Trafikverket and VASYD are responsible for two systems each), which resulted in 13 systems affected.

The concept of cascading effects is something the respondents could grasp, with little effort of explaining, which is helpful. The other terminology could be explained as well, even though it is hard to explain it in exactly the same way every time. This of course might impact the results a bit, since the understanding of the questions may differ.

Interviewing is a technique that can be trained, and as such, the interviews will probably increase in quality the more experienced the researcher is. This was noticed slightly during the case study, with more experience it was for example easier to explain the terminology in a way the respondents would understand.

9 Revised method



The method proposed in chapter 7 works well in many aspects: the use of media to identify systems involved in the event, the semi-structural interviews provided information about originating systems, dependent systems, conditions, dependencies, consequences and served as an introduction of the subject and terminology to the involved persons. The counterfactual reasoning also provided some extra information.

The suggested method for structuring information also performed reasonably well, no problems arose when structuring the interviews into STEP-diagrams one by one, but the aggregation of them all into one for the whole event required some effort.

However there are some issues that need to be addressed, primarily the lack of time data and spatial extent. Also, sometimes the effects mentioned were very general and could be specified better. Here, a follow-up conversation, for example via mail or by an extra meeting, with questions directed towards time, spatial extent and quantification of the cascading effects is suggested. This will be easier now since a contact is already established, many organisations spontaneously offered to help out with additional questions. With the questions, the map of effects that emerged from the interview should be attached, since this will give respondents a chance to correct errors or misinterpretations that might have occurred during interviews, or provide additional information, which will increase the overall quality of the study.

Another issue that arose was the use of cascading effects that did not occur, due to a condition that prevented it, so called near misses. It is believed that these effects could be treated almost as a real effect, because parallels can be drawn to occupational safety management, where they use smaller incidents as near misses of a more serious accident. The theory is that if smaller incidents are prevented the serious accidents should be as well (Kjellén, 2000, p.154f). Another argument for using these near misses, is that the conditions that prevented the effects this time might not be present during the next event.

The new information about time and spatial extent should be integrated into the STEP-diagram. This can be done simply by adding it with text into the boxes of each cascading effect. Alternatively the time could be indicated on the x-axis, as in the original version of the STEP-diagram, and the boxes would then stretch from the starting time until the effect ended. As for the spatial extent, a possible solution would be to use a nominal scale such as: local, regional, national or international effect.

The method described in chapter 7 did not contain any way of analysing the information, as it is not the focus of this thesis. However, the product of said method, the adapted STEP-diagram, should allow for a smooth inputting into a database. From there, the use of statistical methods could possibly provide interesting patterns or insights.

The revised method has not yet been tested due to the limited time available, however it is believed that the revised method will provide information of all the required characteristics. That said, it would probably never be able to provide a *complete* recollection of an event, due to the complexity of the systems involved. Figure 10 provides an overview of the method, step by step.

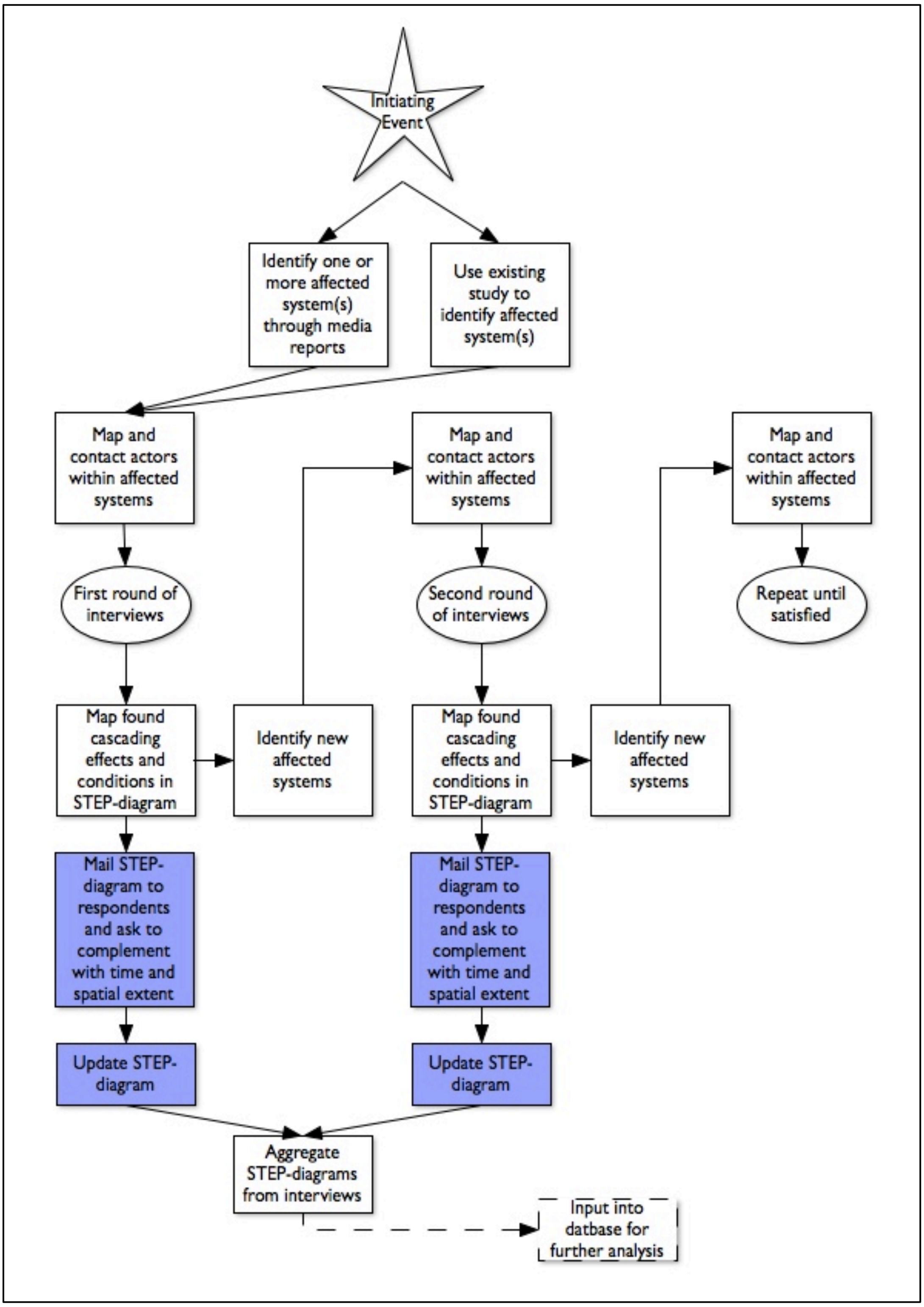


Figure 10. An overview of the revised method. The interview rounds can be repeated until the researcher is satisfied with the results or until the time cost outweighs the benefit. The blue boxes are additions to the original method.

10 Discussion

Here, the focus lies on the author's own reflections regarding various parts of the thesis. This includes subject such as: findings, problems, experiences, beliefs and more.

First out is the general work process, followed by the use of the CascEff projects definitions and system boundaries. The third section will discuss the findings of literature review of existing investigation methods. The next section covers the thoughts regarding the application of the method on the Malmö flooding, followed by a section dealing with the revised method. Lastly, suggestions for further research are presented.

10.1 Work process

The work process provided structure both for the work and the report, in a helpful way. However, it was not followed exactly as presented, since some of the activities were performed simultaneously, for example the literature review of incident investigation methods and the other methods gathering information.

The proposal, application, evaluation and revision of a method is a process that can be performed several time in order to refine it. In this thesis only one iteration was performed, if there were more time available a second iteration would have been done.

10.2 Definitions and system boundaries

The use of existing definitions and terminology from the CascEff project has had its benefits in this thesis; it saved a great deal of time compared to developing it on your own, it makes use of existing research and it has been developed by several researchers, which usually results in a more well thought through product than a single person could produce. This means focus can be shifted towards developing the method and apply it on a case instead.

On the other hand it reduces the freedom of defining everything as you would like and it might not be the best possible definition out there. Another potential problem is the possibility of misinterpreting the terminology and use the terms in a faulty way or out of the proper context. It is however believed the definitions used in this thesis are well aligned with the purpose.

The CascEff definition of cascading effects, its characteristics and system boundaries has proven to be useful. Some ambiguities arose when mapping cascading effects according to the system boundaries, since the boundaries are not very clearly defined. However, defining system boundaries is a whole field of science on its own and at some point one has to balance detail and precision versus time and pragmatism. It is not very practical to have a hundred clearly defined systems to chose as originating or dependent system, even though it would increase the level of detail of the cascading effects.

10.3 Existing incident investigation methods review

The review covers 14 different investigation methods, each presented shortly. The presentations could have been longer, but they are not the main focus of this thesis. Using the two existing reviews as a start, allowed for faster in-depth studying of each investigation method.

It is no surprise that there are few of these methods suitable for investigating cascading effects, since that is not what they were designed for. They are designed to answer the question “What caused the accident?” and not “What did the accident cause?”. However, some of the methods proved useful anyway, especially the STEP-diagrams method of organising information of the accident. This was adopted almost in its entirety, but with more information than the original version provided.

Many of the investigation methods included interviews as way to gather information of the accident and this was also used in the method for investigating cascading effects. But given the timeframe of this thesis (a few months) and the timeframe of incident investigations (often years when investigating bigger events), shorter interviews had to be made.

10.4 Application of method

The choice of the Malmö flooding as a case was made both because it was clear there would be cascading effects, some of which were reported in the news, and of convenience since the city is located nearby the university. Another deciding factor was that the event was not that big, on the large scale of things. This was intentional, so it would fit the timeframe of the thesis.

The interviews proceeded relatively well, considering the lack of experience with interviews on my behalf. The amount of useful information provided from each organisation varied, this could be due the organisations knowledge, which organisation was most vulnerable, how the questions were phrased and understood, the interpretation of the answers or a number of other reasons.

There results from the case study shows that there is information to be found regarding cascading effects, at least given the definitions and terminology used. It also seems like it provides some more depth than a regular study of post assessment reports, even though the sample is by no way satisfactory to draw any conclusion that this is always the case.

Something that might have affected the results from the study is the deviation in how the questions were asked, it is hard to keep to the scripted questions as it is, and when the respondent did not get what you were asking, further explanation is required. Needless to say, the way terms were explained varied from time to time. Another issue is that the participating organisations have relationships with each other, which I felt triggered a mild in-group bias in the responses. Such things are hard to confirm though. The interviews were conducted in Swedish, since it is everyone's native language, and the answers were translated into English, so there is always the possibility of bad translations, adding extra meaning or losing some of the meaning.

Another interesting aspect of the study is the amount of conditions found, affecting both systems as whole and particular cascading effects, more than I anticipated would be possible. Some of the conditions were predicted before the study was conducted, such as the importance of timing and weather conditions, but one type that was overlooked and that was the organisations ability to increase its working capacity. This was often dependent on the availability of extra personnel and was brought up a lot by the organisations.

The use of counterfactual reasoning in the interviews generated some extra results, which might not otherwise been brought up by the respondents. In some interviews it appeared naturally, before asking the specific questions to lead them. Even though most humans do this frequently, it is probably a good idea to specifically direct the respondents towards this way of thinking since it is easy to be trapped into thinking only of actual facts. Counterfactual reasoning could probably be used even more than suggested here, and also in other research situations.

10.5 Revised method

The changes suggested in the revision of the method are supposed to remedy the flaws detected during the case study. It was quickly obvious that asking questions about time, exact effects and spatial extent every time a cascading effect were mentioned would disrupt the flow of the interviews severely.

The information is still sought after, thus a follow-up interview or mail conversation was suggested. It uncertain if this will work, since there was not enough time to send out request, give them enough time to respond and then update the results. There should be good chances of success though, since the respondents now know the terminology and have time to prepare a more detailed answer than is possible in an hour-long interview. On the other hand it is uncertain if they are willing to use even more of their time on a study like this without being compensated for it, for larger studies funding for this might be a requirement.

Problem still exist with the revised method, however. The time required to conduct a series of interviews and follow-up conversations is definitely longer than the time it takes to analyse reports, even though the amount of information gathered seems to be larger. Another problem is that interviews are hard to standardise and the quality depends greatly on the skills of the interviewer, so it is preferred that the person(s) conducting the study has some previous experience, something I felt I was lacking. A third problem has to do with the level of detail of the consequences, if the focus is on societal level, some of the results surely can be disregarded. This can be done afterwards, but also means that more information is gathered than is needed.

Overall the revised method should, despite its flaws, provide a solid foundation for further studies of cascading effects, especially when the written material is scarce. Possibly also as an alternative when the amount of written material is overwhelming, if one could find the best candidates for an interview, it might be faster than going through a huge pile of reports.

10.6 Usability

The method itself should be usable for researchers who are doing empirical work on cascading effects, as a complementary tool used with post-disaster assessments and the like. Perhaps post-disaster investigation teams or could also have use of this method, when conducting their investigations

The results from the method could, with a more substantial amount of cases, be used to identify especially vulnerable systems, as a part of a long-term protection plan for critical infrastructure. An additional use is to provide support, or inspiration, to municipal emergency response planners, by having examples of cascade effects that are possible. Other long-term uses include modelling of cascading effects or a development of a decision support tool, where incident commanders can get information about potential cascading effects in the situation they are in, thus giving them a better chance of implementing effective countermeasures.

10.7 Further research

The development of a firm, widely agreed definition of cascading effects and its terminology should be a priority. If there were a widespread terminology that incident investigators could use to write a small chapter specifically dedicated to cascading effects in their reports, it would drastically increase the amount of information that could be analysed. This would be useful for all researchers of the subject and would most likely increase the understanding of cascading effects.

Another area of interest is when there are conflicting perceptions of an event, regarding responsibilities and dependencies between the different systems. How does one deal with such situations? Whose perception should be presented? Both?

As for the method presented in this thesis, more applications, evaluations and revisions would lead to a more refined research method.

11 Conclusion

With the definition and terminology used, a suitable method for studying cascading effects should provide information about the:

- Originating system
- Dependent system
- Dependency type
- Consequences on the dependent system(s)
- Starting and ending time of the cascading effect
- Spatial extent
- Cascade order
- Conditions

Knowing these characteristics should provide a solid foundation for a larger analysis of cascading effects, when several more events have been studied.

The literature review of incident investigation methods showed that none of the reviewed methods would meet these criteria fully, often due to the fact that they do not look beyond the initial incident. However, from these methods, semi-structured interviews were deemed to be the most suitable way to gather information and an adapted version of the STEP diagram for structuring information. Ideas from counterfactual reasoning were used to better capture conditions during interviews.

The original method consisted of the following steps:

- Identify potentially affected systems through media reports.
- Map and contact actors within systems.
- Conduct semi-structured interviews, focusing on: dependencies from and to other systems, consequences of the dependencies, time and spatial extent included, and mitigating and aggravating conditions.
- Map the found information into a STEP-diagram as shown in Figure 6 for each interview. Contact newly found systems for another round of interviews.
- Aggregate all the STEP-diagrams from the interviews into one, picturing the event as a whole.

A case study on the flooding of Malmö late summer of 2014 revealed some flaws of the method, it had problems determining the time data, the spatial extent and sometimes the effects were not very detailed. However it also showed that it was possible to gather and structure a sizeable amount of information in the suggested way.

With experience from the case study, the method was developed further, in order to better meet all the criteria and to do it in a more practical way. A follow-up conversation was added, preferably via email, where the researcher can supply the interviewees with a STEP-diagram of the interview and ask for details of time, spatial extent and consequences.

Even though the revised method has not been fully tested, the concept seems to work: it is certainly a viable method for a more in-depth investigation of the cascading effects of an event. An advantage with this method is its ability to include “near misses”, which gives bonus data if they are treated almost as an equal to an actual effect. Also, the conditions provided by this method give a better understanding of why a cascading effect occurred and could possibly be used to prevent future cascading effects.

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13 Appendix A – Interview responses

Here, all the responses from the interviews are presented in its original form. The original interview support is found in Appendix C – Interview support (blank).

VA-SYD

Date: 2014-11-14 Name: Marianne Beckman, Ulf Nyberg

Sector: Water supply/Sewage

Organisation: VA-SYD

Tell me about the ordinary activities in your organisation

Freshwater supply dept. (pipe network)

Waste water dept. (including day water)

During the event, did your organisation experience trouble caused by another organisation not related to your own field of operations?

Dependencies	Type	Free text
Power systems		Pump stations needs power (all worked during the event though)
Telecommunication		Telephones: Organising personnel etc (minor issues) Mail (also worked)
Road transportation		Getting to and forth to pump stations etc. Water hindered mobility
Governmental systems		How the municipal technical department works affects the work of VA-SYD.

Emergency response system		SOS-alarm handles all emergency calls during evenings/weekends (no problem though)

Dependencies TO other systems:

Road transportation: VA-SYD responsible for some pumps that removes day water from roads such as under viaducts. Some did not work, some were flooded, resulting in flooded roads. Rail transportation: same as road, but less extensive (no problem during the event) Health care: hospital flooded cellars Public: flooded cellars in many houses Education: some schools flooded (also from sewage to water supply, did not happen, but was close)

Are there any conditions that affected the effect or the possibility of the dependencies?

Conditions	
Mitigating	Aggravating
Happened on a weekend, which meant that people stayed at home, made it easier to work	Contact with municipality not very good.
End of vacations, thus extra personnel were at home and could be used	

Mobilisation of personnel went smooth, enough available	

What if the flooding happened during a Wednesday? Would the situation be better or worse for your organisation?

Most probably more disruptions, but not so much for the organisation.

If the sea level were higher it could have had a very negative impact on the event.

Same if the ground was more saturated or if two similar events happened in close proximity.

What would have improved your organisations ability during the event?

Could not think of anything in particular, overall happy with the way they handled the situation.

RSYD

Date: 2014-10-24 Name: Mats Nilsson

Sector: ERS

Organisation: RSYD

Tell me about the ordinary activities in your organisation

During the event, did your organisation experience trouble caused by another organisation not related to your own field of operations?

Dependencies	Type	Free text
Power systems		Power outage at Kronprinsen: people stuck in elevator, required resources

Sewage system		Backflow lead to extra workload, people calling and receiving help from RSYD if RSYD was able to.
Road transportation		Troubles cooperating (required transportation) and get to accidents, fires etc. Increased response time.

Dependencies TO other systems:

EON: District heating plant threatened to be flooded, the emergency services place pumps. Would probably be flooded if no help had arrived.

Malmö Hospital: Pumping to avoid flooding of hospital buildings

Are there any conditions that affected the effect or the possibility of the dependencies?

Conditions	
Mitigating	Aggravating
Were able to call in extra personnel.	Harder to cooperate with municipality during weekends, they do not have much personnel on call.
Prioritisations and plans for this kind of event already existed.	No early warning from the Swedish meteorological institute.

What if the flooding happened during a Wednesday? Would the situation be better or worse for your organisation?

+ There would be more personnel available, and much faster.

- More traffic, people going to work. Would probably lead to more cars getting stuck and even harder to get by on the roads.

In total: would probably affect the organisation to the worse

What would have improved your organisations ability during the event?

Better cooperation with other involved actors, including a quick response staff. Such cooperation exists to some extent, but should be utilised more often.

Trafikverket

Date: 2014-11-25 Name: Nina Börstad, Rikard Andersson

Sector: Road Transportation/Rail Transportation

Organisation: Trafikverket

Tell me about the ordinary activities in your organisation

Responsible for the road and rail network in south of Sweden

During the event, did your organisation experience trouble caused by another organisation not related to your own field of operations?

Dependencies	Type	Free text
Initiating event		Railroad tracks flooded at Svågertorp, no goods trains for a day Close: whole IT-system almost flooded, Condition: pumps already installed 1 extra had to be put in Road: Almost all major roads to and from Malmö flooded,

		E6 Vellinge closed because of slide
Sewage system		Pump that clears viaduct from water, stopped working due to flooded electrical component: blocked road
The public		People moved roadblocks => Had to send out personnel (and police helped) continuously to the same places to restore them also danger to drivers + more people got stuck in water, affecting rescue services

Dependencies TO other systems:

From road to public: really hard to get from/to Malmö, even harder on the bridge
From road to rail: train easiest way to get over the Denmark-Sweden bridge, increased load
From road to business: blocked roads meant longer transportation and delays

Are there any conditions that affected the effect or the possibility of the dependencies?

Conditions	
Mitigating	Aggravating
6 trucks was out in the field working with a closed road in Lund (20-30 min from Malmö), redirected to handle flooding	There were some technical disruptions in the internal telecommunication servers

Trafikverket uses the same personnel for incident management on roads as the municipality (they have different responsibilities), which leads to a better overview of whole Malmö, and not only the state roads	No full effect available on rail power supply (reason unknown) => trains had to accelerate slower than normal (small delays)
	No early warning from weather institutes

What if the flooding happened during a Wednesday? Would the situation be better or worse for your organisation?

Pros: More personnel available

Cons: more traffic on road/rail

Overall: most probably worse

What would have improved your organisations ability during the event?

An early warning would have lead to more on-call personnel to handle the event

Region Skåne

Date: 2014-11-17 Name: Stefan J Persson

Sector: Healthcare

Organisation: Region Skåne

Tell me about the ordinary activities in your organisation

Provides healthcare for Skåne, the hospital serves Malmö with surroundings

During the event, did your organisation experience trouble caused by another organisation not related to your own field of operations?

Dependencies	Type	Free text

Initiating event		Electrical switchgear flooded in one building leading to evacuation of 68 patients. A heating central almost flooded, as well as another switchgear – threatening 300 patients. Over 2500 cubic meter of water in buildings, 20 elevators drowned. The central for sterile equipment flooded.
Business		Without PULS (has large trucks with pumps etc) the second switchgear would be flooded, danger to patients.
Emergency response system		Without the rescue services the second switchgear would be flooded, danger to patients.

Dependencies TO other systems:

Are there any conditions that affected the effect or the possibility of the dependencies?

Conditions	
Mitigating	Aggravating

Preparedness plan worked well	No premade contracts with firms like Puls
	No pumps on their own
	Hard to contact VA-SYD in order to co-operate
	Hospital extra sensitive to the sewage water that flooded the buildings.

What if the flooding happened during a Wednesday? Would the situation be better or worse for your organisation?

Maybe easier to get hold of more external resources quicker

If anything: a bit better

What would have improved your organisations ability during the event?

A small emergency wagon with one or two big pumps

Malmö Stad

Date: 2014-11-27 Name: Magnus Fjällström

Sector: Government (local level)

Organisation: Malmö Stad

Tell me about the ordinary activities in your organisation

Malmö Stad is responsible for elderly care, education, roads, waste disposal and more in the municipality.

During the event, did your organisation experience trouble caused by another organisation not related to your own field of operations?

Dependencies	Type	Free text
Initiating event		Garage with vehicles for school transport for special needs children flooded (great material costs) Roads flooded and viaducts flooded Municipal IT/telecom system flooded High rise building basement flooded, no power Flooded basements in hospital
Power system		No power in high rise building led to complications with elderly care clients that needed to be evacuated
Health care		Elder care clients whose caretakers could not reach them worried Planning to take care of many patients due to possible evacuation of a hospital building
Road transportation		Elderly care personnel could not reach all clients
The public		Worried people, or people with normal flooding problems called the emergency line of social services (dealing with abused children etc). People with real social services incidents to report had troubles getting through.

Dependencies TO other systems:

Municipality didn't manage to keep roads open, which affected the works of emergency response services Some of the municipal buildings without IT, among them a clinic Problems with common operational picture, especially the closed off roads. Information needed by emergency response services

Are there any conditions that affected the effect or the possibility of the dependencies?

Conditions	
Mitigating	Aggravating
Were able to call in extra personnel	No early weather warning
Could reroute municipal IT/telecom to other servers that were not flooded	
Taxis could provide school rides for the special needs children	

What if the flooding happened during a Wednesday? Would the situation be better or worse for your organisation?

+ easier to get more personnel, able to warn different departments to secure sensitive stuff from the water (less material damages), the school buses would not be in the flooded garage

- More vulnerable to the telecom downtime

What would have improved your organisations ability during the event?

Early warning from the meteorological institute would have indicated the seriousness of the situation earlier.

Länsförsäkringar

Date: 2014-11-17 Name: Heléne Nilsson

Sector: Finance (insurance)

Organisation: Länsförsäkringar

Tell me about the ordinary activities in your organisation

Insures buildings etc

Approves compensation for damages

During the event, did your organisation experience trouble caused by another organisation not related to your own field of operations?

Dependencies	Type	Free text
Power systems		Power losses at some sites made it harder to pump out water, increased damages. Ex Kronprinsen
Sewage system		Flooded cellars caused a lot of damages to clients, extra work and cost for the organisation
Business		Contractors for sanitation, drying of houses and reconstruction. Org. does not have that expertise themselves. Limits the amount of support they can give customers

Dependencies TO other systems:

Public – needs approval of costs from the insurance company before they can start reparations etc. Business – contractors that restore the building to habitable conditions (sanitation, drying, construction) needs an OK from the insurance company before they start any work, to insure they get paid.

Are there any conditions that affected the effect or the possibility of the dependencies?

Conditions	
Mitigating	Aggravating
The organisation had experience from several storms, which they utilised in this case.	No early warning – took a day to mobilise personnel.

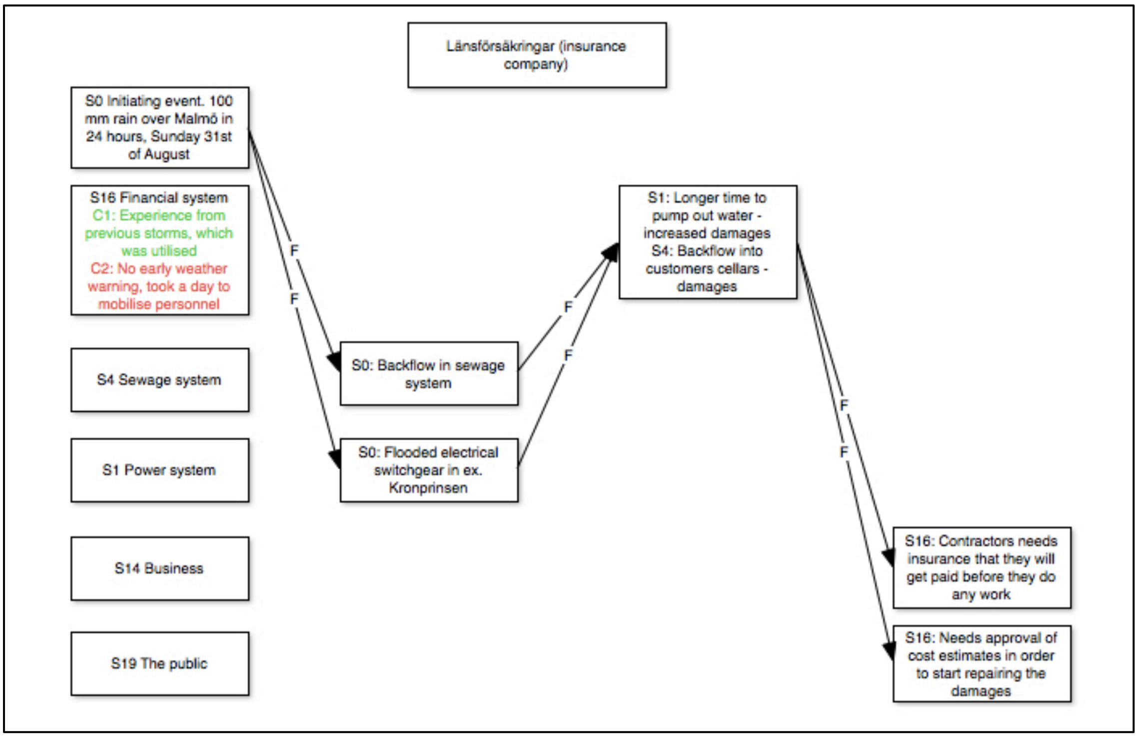
What if the flooding happened during a Wednesday? Would the situation be better or worse for your organisation?

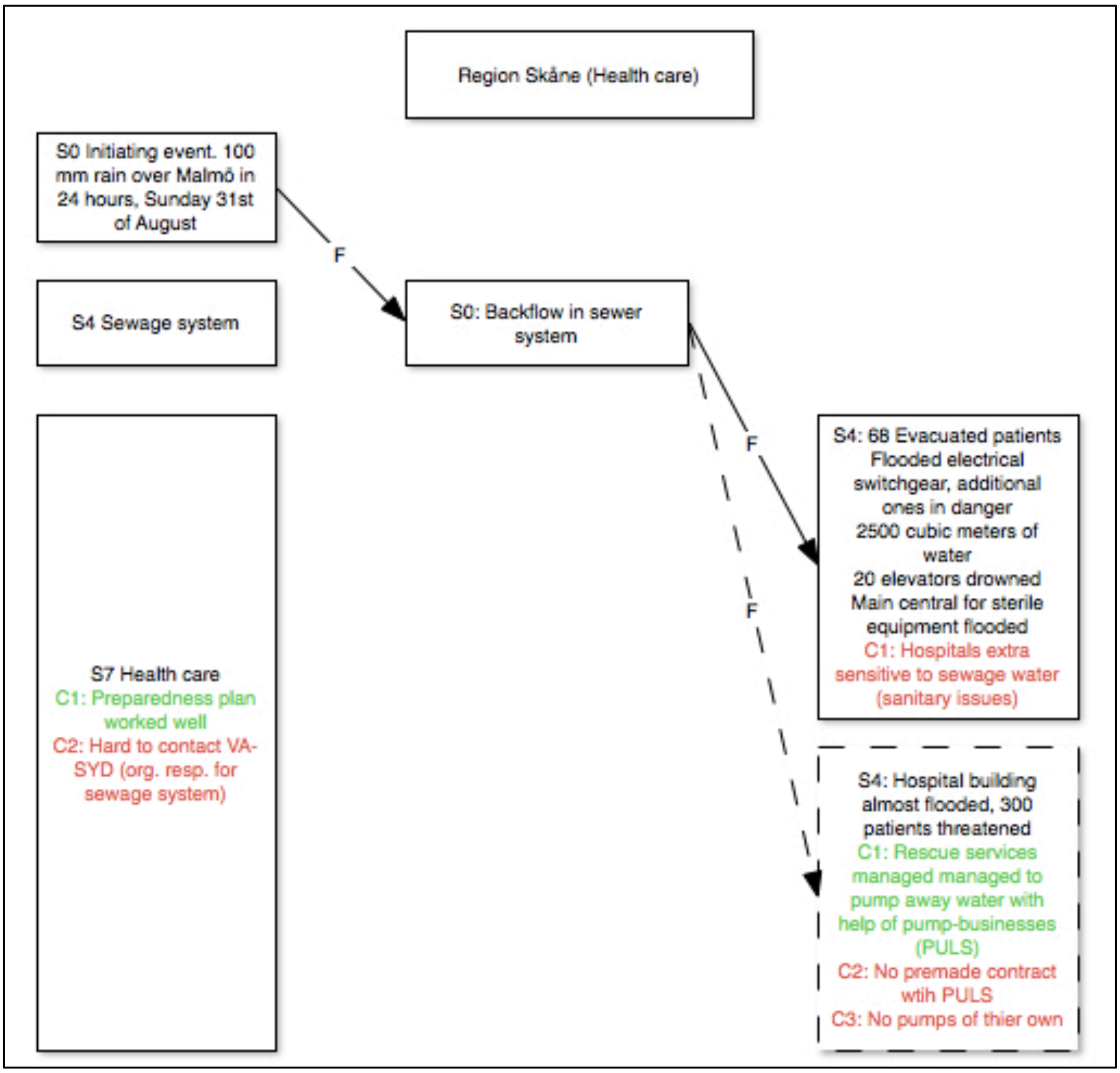
Initially better – there would be more personnel available to quickly take care of the large amount of incoming calls

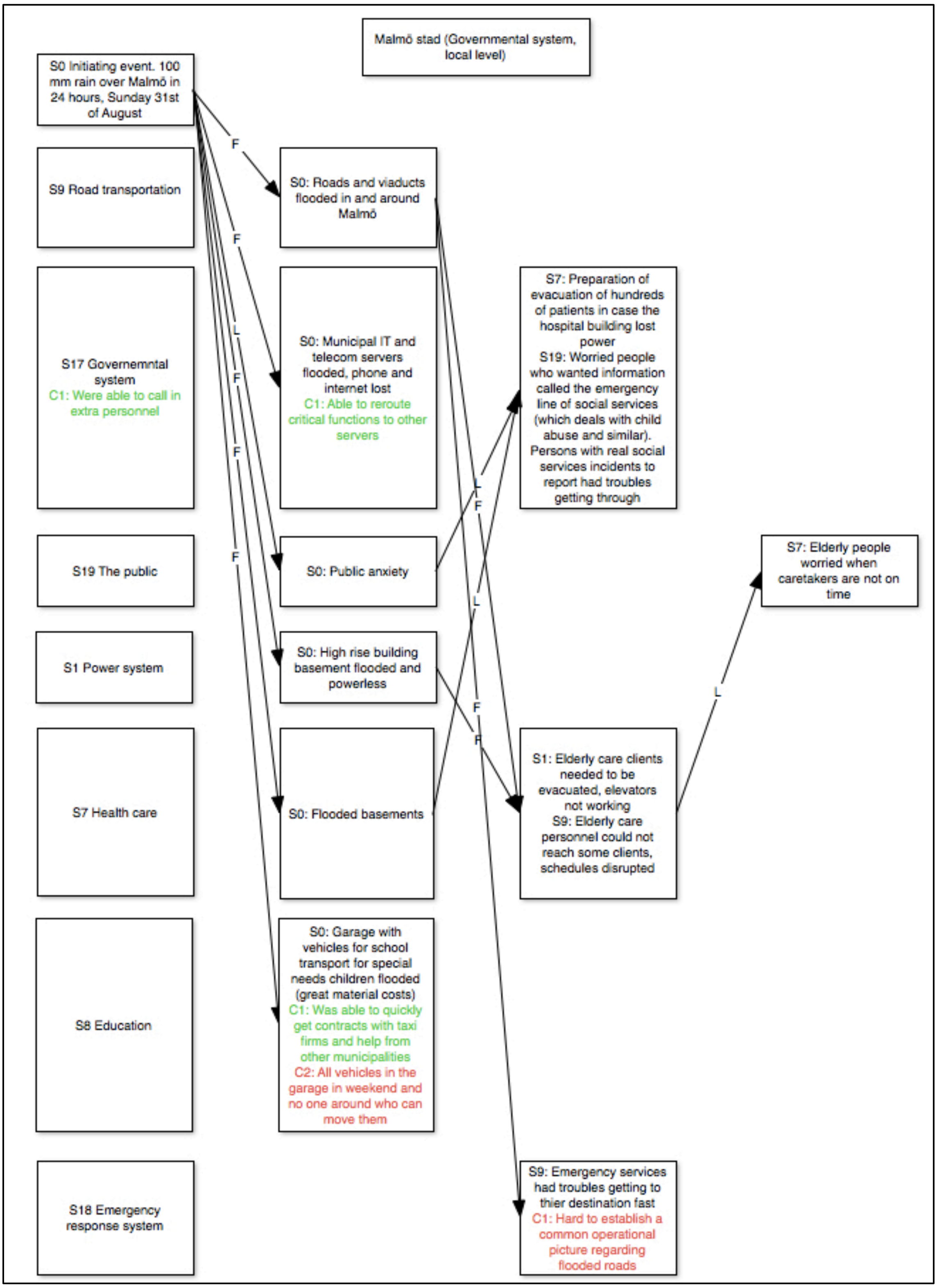
What would have improved your organisations ability during the event?

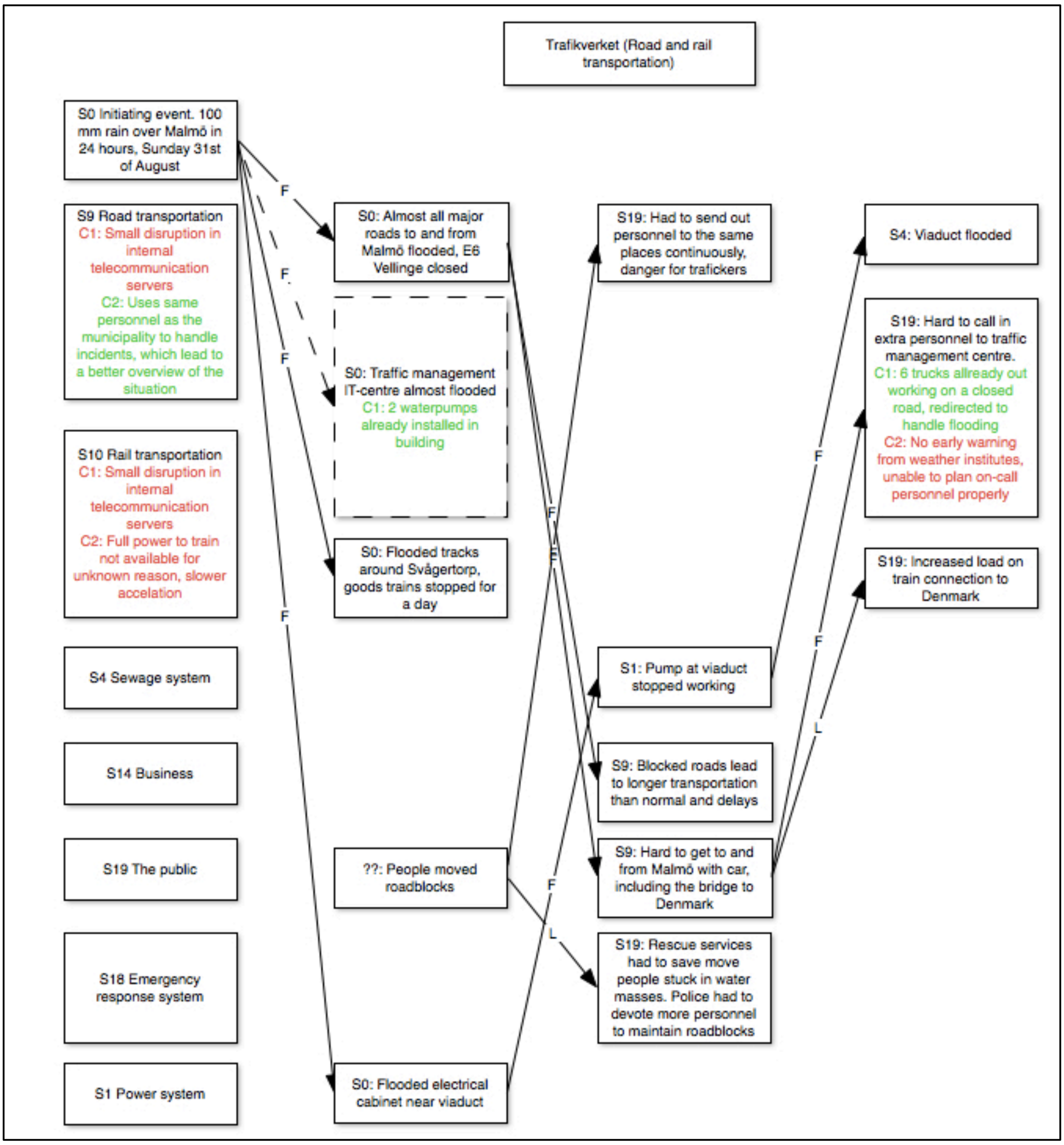
Preparedness in form of a predefined group of workers who will deal only with a flooding event and which are trained regularly for dealing with flooding damages. Already implemented today.

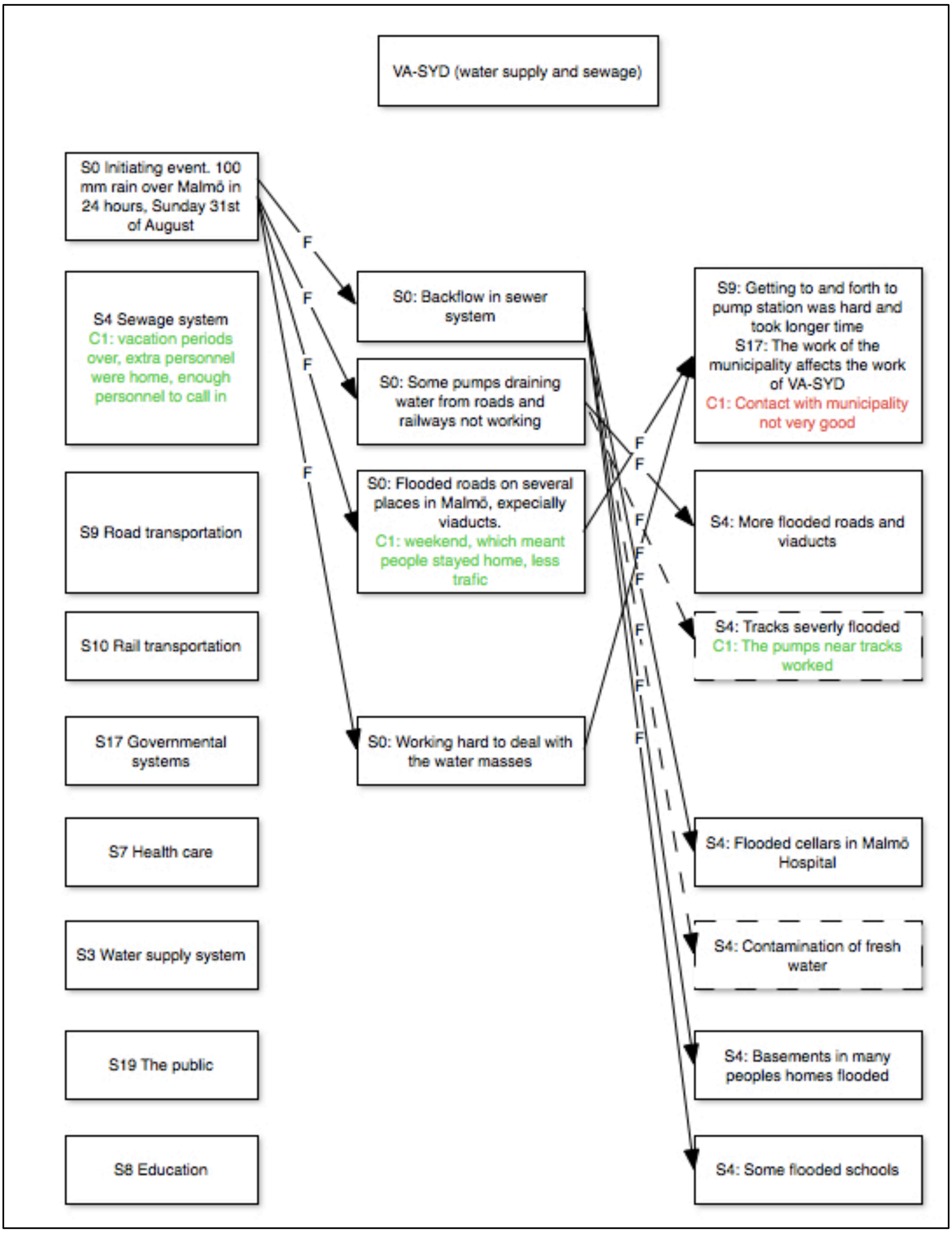
14 Appendix B – Interview STEP diagrams

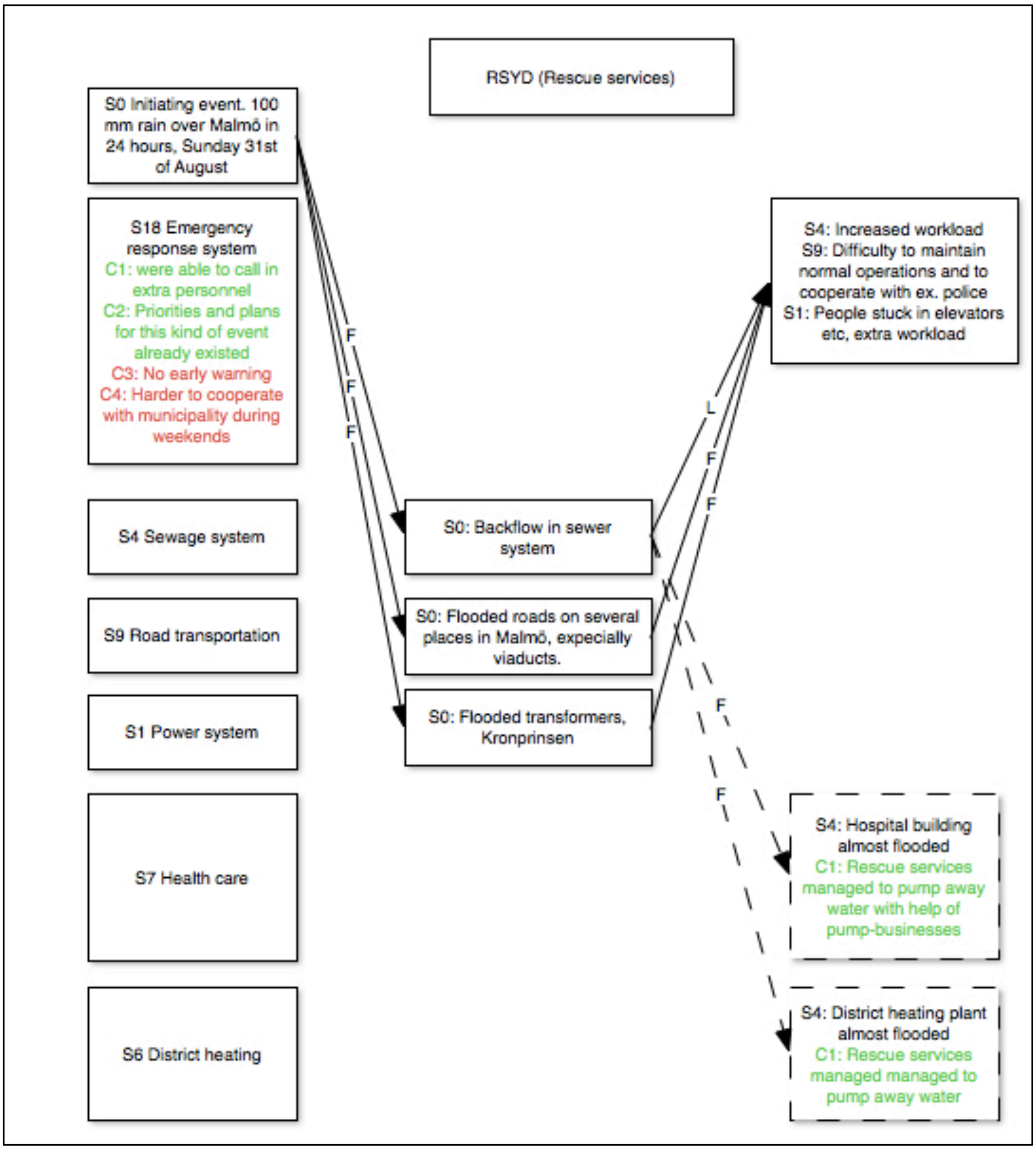



Region Skåne (Health care)
S0 Initiating event. 100 mm rain over Malmö in 24 hours, Sunday 31st of August
S4 Sewage system
S7 Health care
C1: Preparedness plan worked well
C2: Hard to contact VA-SYD (org. resp. for sewage system)
F
S0: Backflow in sewer system
F
F
S4: 68 Evacuated patients
Flooded electrical switchgear, additional ones in danger
2500 cubic meters of water
20 elevators drowned
Main central for sterile equipment flooded
C1: Hospitals extra sensitive to sewage water (sanitary issues)
S4: Hospital building almost flooded, 300 patients threatened
C1: Rescue services managed managed to pump away water with help of pump-businesses (PULS)
C2: No premade contract wtih PULS
C3: No pumps of thier own


Malmö stad (Governmental system, local level)
S0 Initiating event. 100 mm rain over Malmö in 24 hours, Sunday 31st of August
S9 Road transportation
S17 Governemntal system
C1: Were able to call in extra personnel
S19 The public
S1 Power system
S7 Health care
S8 Education
S18 Emergency response system
S0: Roads and viaducts flooded in and around Malmö
S0: Municipal IT and telecom servers flooded, phone and internet lost
C1: Able to reroute critical functions to other servers
S0: Public anxiety
S0: High rise building basement flooded and powerless
S0: Flooded basements
S0: Garage with vehicles for school transport for special needs children flooded (great material costs)
C1: Was able to quickly get contracts with taxi firms and help from other municipalities
C2: All vehicles in the garage in weekend and no one around who can move them
S7: Preparation of evacuation of hundreds of patients in case the hospital building lost power
S19: Worried people who wanted information called the emergency line of social services (which deals with child abuse and similar). Persons with real social services incidents to report had troubles getting through
S1: Elderly care clients needed to be evacuated, elevators not working
S9: Elderly care personnel could not reach some clients, schedules disrupted
S9: Emergency services had troubles getting to thier destination fast
C1: Hard to establish a common operational picture regarding flooded roads
S7: Elderly people worried when caretakers are not on time
F
L


Trafikverket (Road and rail transportation)
S0 Initiating event. 100 mm rain over Malmö in 24 hours, Sunday 31st of August
S9 Road transportation
C1: Small disruption in internal telecommunication servers
C2: Uses same personnel as the municipality to handle incidents, which lead to a better overview of the situation
S10 Rail transportation
C1: Small disruption in internal telecommunication servers
C2: Full power to train not available for unknown reason, slower accelation
S4 Sewage system
S14 Business
S19 The public
S18 Emergency response system
S1 Power system
S0: Almost all major roads to and from Malmö flooded, E6 Vellinge closed
S0: Traffic management IT-centre almost flooded
C1: 2 waterpumps already installed in building
S0: Flooded tracks around Svågertorp, goods trains stopped for a day
??: People moved roadblocks
S0: Flooded electrical cabinet near viaduct
S19: Had to send out personnel to the same places continuously, danger for trafickers
S1: Pump at viaduct stopped working
S9: Blocked roads lead to longer transportation than normal and delays
S9: Hard to get to and from Malmö with car, including the bridge to Denmark
S19: Rescue services had to save move people stuck in water masses. Police had to devote more personnel to maintain roadblocks
S4: Viaduct flooded
S19: Hard to call in extra personnel to traffic management centre.
C1: 6 trucks allready out working on a closed road, redirected to handle flooding
C2: No early warning from weather institutes, unable to plan on-call personnel properly
S19: Increased load on train connection to Denmark
F
L


VA-SYD (water supply and sewage)
S0 Initiating event. 100 mm rain over Malmö in 24 hours, Sunday 31st of August
S4 Sewage system
C1: vacation periods over, extra personnel were home, enough personnel to call in
S9 Road transportation
S10 Rail transportation
S17 Governmental systems
S7 Health care
S3 Water supply system
S19 The public
S8 Education
S0: Backflow in sewer system
S0: Some pumps draining water from roads and railways not working
S0: Flooded roads on several places in Malmö, expecially viaducts.
C1: weekend, which meant people stayed home, less trafic
S0: Working hard to deal with the water masses
S9: Getting to and forth to pump station was hard and took longer time
S17: The work of the municipality affects the work of VA-SYD
C1: Contact with municipality not very good
S4: More flooded roads and viaducts
S4: Tracks severly flooded
C1: The pumps near tracks worked
S4: Flooded cellars in Malmö Hospital
S4: Contamination of fresh water
S4: Basements in many peoples homes flooded
S4: Some flooded schools
F


RSYD (Rescue services)
S0 Initiating event. 100 mm rain over Malmö in 24 hours, Sunday 31st of August
S18 Emergency response system
C1: were able to call in extra personnel
C2: Priorities and plans for this kind of event already existed
C3: No early warning
C4: Harder to cooperate with municipality during weekends
S4 Sewage system
S9 Road transportation
S1 Power system
S7 Health care
S6 District heating
S0: Backflow in sewer system
S0: Flooded roads on several places in Malmö, expecially viaducts.
S0: Flooded transformers, Kronprinsen
S4: Increased workload
S9: Difficulty to maintain normal operations and to cooperate with ex. police
S1: People stuck in elevators etc, extra workload
S4: Hospital building almost flooded
C1: Rescue services managed to pump away water with help of pump-businesses
S4: District heating plant almost flooded
C1: Rescue services managed managed to pump away water
F
F
F
L
F
F
F
F

15 Appendix C – Interview support (blank)

Interview-support

Date: Name:

Sector:

Organisation:

Tell me about the ordinary activities in your organisation

During the event, did your organisation experience trouble caused by another organisation not related to your own field of operations?

Dependencies	Type	Free text
Power systems		
Telecommunication		
Water supply system		
Sewage system		

Oil and gas system		
District heating		
Health care		
Education		
Road transportation		
Rail transportation		
Air transportation		
Sea transportation		
Agriculture		
Business		
Media		

Financial system		
Governmental systems		
Emergency response system		
The public		
Environment		
Political system		

Dependencies TO other systems:

Are there any conditions that affected the effect or the possibility of the dependencies?

Conditions	
Mitigating	Aggravating

What if the flooding happened during a Wednesday? Would the situation be better or worse for your organisation?

What would have improved your organisations ability during the event?

16 Appendix D – Enschede firework disaster

This appendix will shortly introduce the Enschede firework disaster and the results from a document study conducted on the event.

In Enschede, on 13th of May 2000, a fire broke out in a firework warehouse. During the efforts to put out the fire, several explosions occurred, instantly killing four fire fighters and a journalist. In total 24 people were killed, 900 were injured and over 5000 became homeless (Socialstyrelsen, 2004).

The study was conducted with three written sources of information, using no media reports (Socialstyrelsen, 2004; Webbink, 2008; Yanik, 2001). The event was mapped the same way that the interviews in this thesis have been mapped.

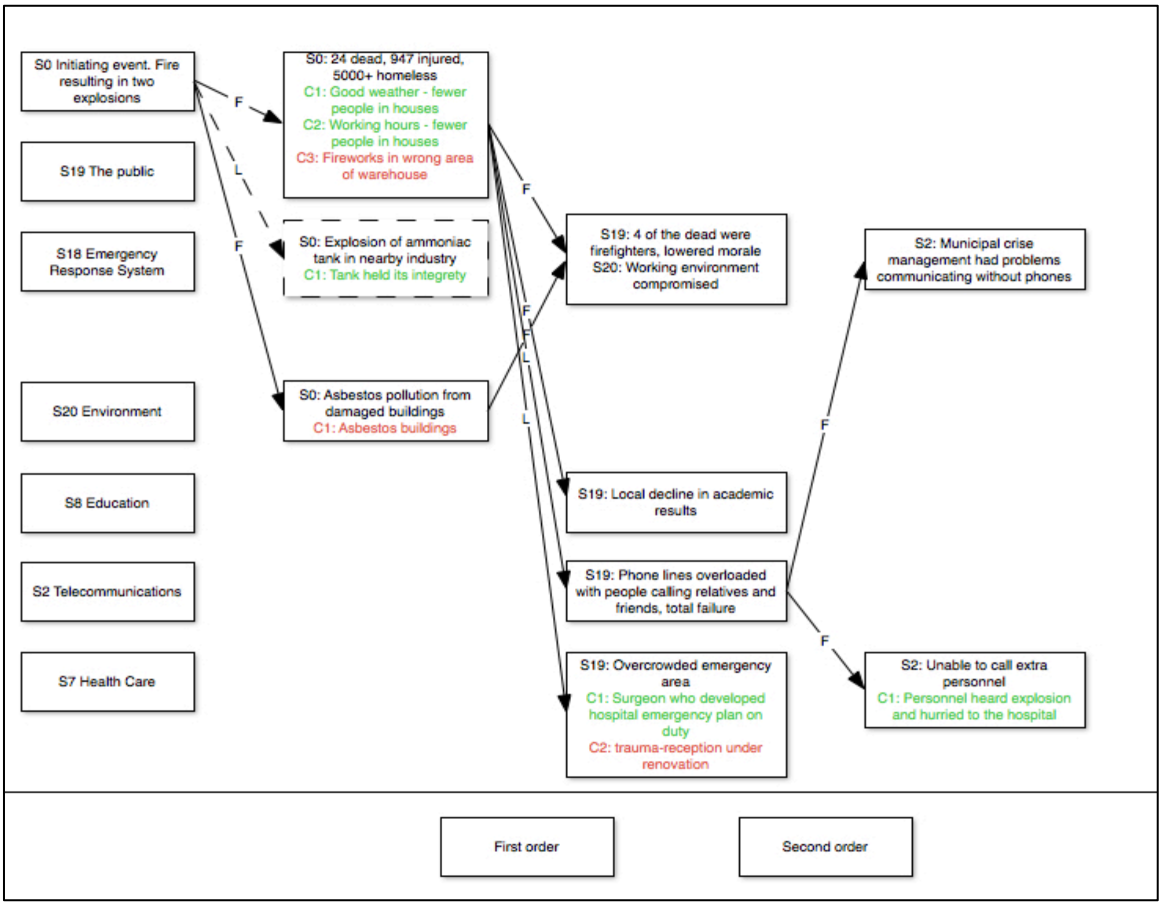


Figure 11. STEP diagram of the Eschede firework disaster.