Department of Human Geography
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Approaches for Preventing Power Outages

- A Case Study into Scania

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Abstract:

In this paper I examine the approaches taken by actors in Scania to improve power reliability and prevent outages. This means that I study what the relevant actors do in order to detect threats and vulnerabilities to the power supply. I also study the measures they take to reduce these risks and prevent outages. From that I draw a conclusion on their approach to the issue. To categorize the organization's approaches I use the Normal Accidents Theory and High Reliability Organization Theory. The information will be gathered by using literature study, interviews and observations. The information gathered is analysed to determine what approach each actor has, the region as a whole has and what patterns that can be discovered in the use of approaches and why that pattern has taken place. Finally I shed some light on how this impacts the reliability of power supply in the region and how the theories' implications can help improve the approaches to power reliability.

The conclusion drawn is that the region's actors as a whole do use the measures implicated by the two theories. But they implement the measures in a context independent manner and with regards to current needs. This leads me to conclude that the actual approach of the region is one of practicality. Generally one actor relies on one type of approach. The utility companies tend to go for the technical answers provided by the Normal Accidents theory and the public organizations tend to implement organizational measures as suggested by High Reliability Organization theory. But applying them in a context independent way reduces the reliability potential. Incorporating a more systematic approach will help in detecting long-term, cross-sectorial risk and help evaluate the measures proposed to deal with these risks.

Power supply

Power outage

Critical infrastructure

Important societal functions

System reliability

Index

Abbreviations:

ISF	Important Societal Function
RVA	Risk and Vulnerability Analysis
NAT	Normal Accidents Theory
HRT	High Reliability Theory
HRO	High reliability Organization
CCA	The Civil Contingencies Agency

Figure 1. A map of Scania and its towns and cities.

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1. Introduction:

Modernity potentially leads to primitivism. This is the paradox of the modern life. Even though we have never lived as comfortably as today, we have never been so exposed to regress to more primitive times. What if the apocalyptic drama series we watch were to come true? It is not unrealistic considering the recent attacks on media websites, the collapse of a communication mast outside the Swedish city of Borås, the dysfunction of the communication network and radar of Stockholm's airports and the temporary shutdown of SOS communications (www.aftonbladet.se). An apocalyptic scenario would be reality if there was a large scale power outage for a longer period of time. As we are creatures of habit we have grown accustomed to the comforts that electricity brings. We have grown accustomed to the constant supply of electricity as if it something to be taken for granted. Not many have prepared to what would happen if the power suddenly came to a stop. This is why it is of critical importance to protect the supply of power and increase awareness of the fragility of modern society.

The problem with a power outage is not just the lack of electricity. There is a wide range of systems and services that are dependent on electricity and which would cease to function in case of a power outage. A power outage would affect the water supply and water disposal, the electronic communications such as TV, internet and mobile phones, the banks and the financial system, fuel supply because the pumps at gas stations are power driven, the hospitals, the emergency response authorities, the industry and all modern offices. The cessation of each of these would in turn also result in the cessation other functions.

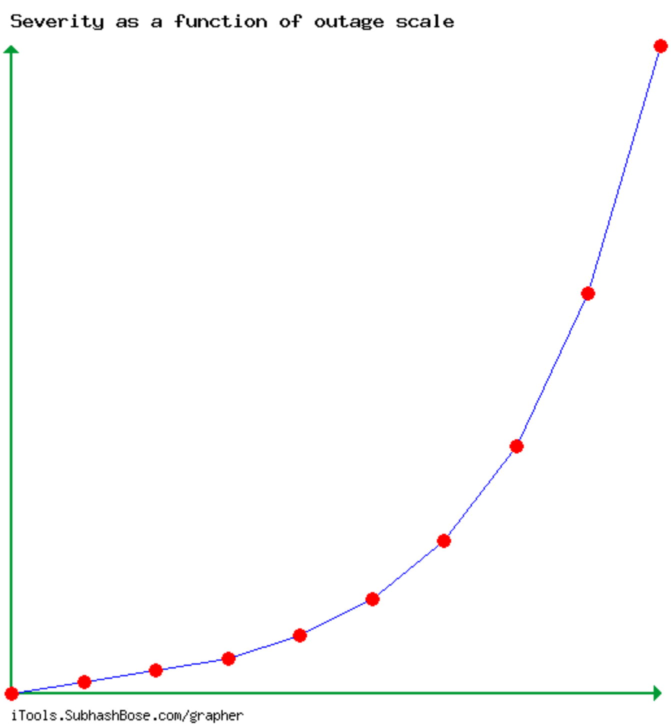

Figure 2. Illustration of a power outage's severity as a function of the outage's scale.

The consequences of a power outage can be said to be exponentially growing in relations to the blackout's area. This is because it becomes harder and harder to repair the outage the larger the scale of the outage is. It also becomes harder to access reserve power from other areas. Fuel for reserve aggregates become more demanded and supply is reduced because the pumps aren't working within the whole of the blacked out area. This is illustrated by figure 2.

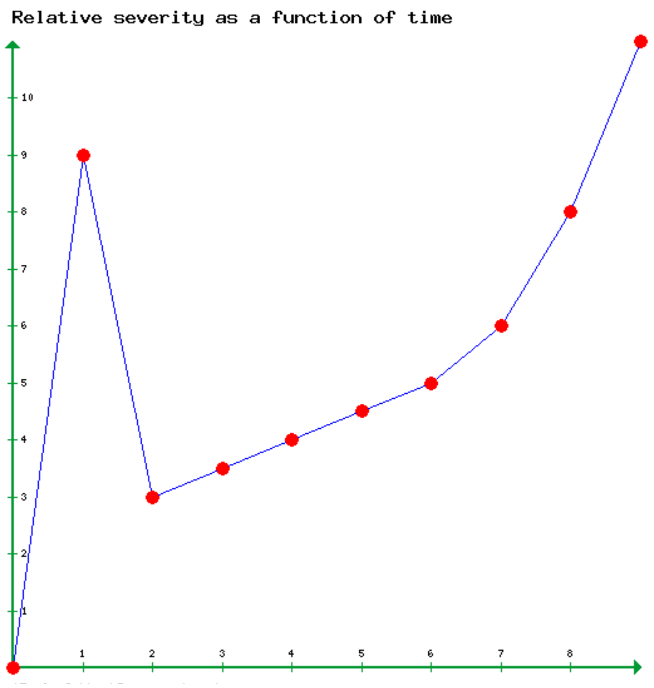

Figure 3. The relative severity of an outage as a function of time.

Another factor which affects the consequences is time. Relative severity measures how conditions are at a certain point in time T, compared to T-1. It measures if things become better or worse. An outage first produces a sharp relative severity increase because of the immediate shutdown of systems and the ensuing discomfort, confusion and chaos. This later goes down as the chock subsides and one gets used to the outage. But the impact of the outage continues to grow larger and worse as the outage continues. This is illustrated in figure 3.

A power outage has dramatic economic, social, psychological, environmental and political effects. One outage was caused by the cyclone Gudrun/Erwin and its costs were measured by the Swedish Energy Agency. On a general scale there were at most during and after the storm 415 000 households without power. Most received power within 24 hours. The average restoration time was 4 days. The total costs for the power companies attributed to clearing, repairing and restoring power is approximated to 1,85 billion kronor (~ 227 million USD). The total costs for the outage are circa 2,7-3 billion (~ 331-368 million USD). Much of these costs were approximated by deriving a reasonable daily cost for the outage for a particular sector and then multiplying it with the number of affected people and multiplying it with the number of days the power was out (Statens energimyndighet, 2005).

As we can see, outages still occur and when it comes to outages the most important thing is to prevent them, reduce the area which is affected and that investing in a robust and reliable system is worthwhile.

With this in mind it becomes obvious the need to research into and solve the issues of power supply. Generally one can say that there are three ways to treat this problem. The first is to reduce the probability of a disruption happening, the second is to reduce its impact if it happens, through early warning of impending disruption or other counter measures, the third is to speed up recovery from a disruption. These are the three phases of power resilience.

In all the phases two theories seem relevant to proceed from in order to improve robustness. The first is to work within the High Reliability Organization Theory (HRT) paradigm which suggests organizational reforms to reduce error. The other way is to research through the Normal Accidents Theory (NAT) which says that complex systems are prone to accidents and in need of a good design to reduce this. To illustrate the difference between them we could say that a NAT theorist would propose parallel systems and redundancy to increase reliability while a HRT theorist would suggest collective diversity in a group in order to use each other's skills in detecting early problems.

2. Purpose, Research Question & Hypothesis:

The main purpose of the paper is to study the approaches taken by actors in preventing power outages in Scania. These approaches will be examined in the light of two theories (the Normal Accidents Theory and the High Reliability Organization Theory). They were originally applied for nuclear power plants and air traffic control systems. Those were the case studies the theories were built upon. Both theories came out shortly after the Three Mile Island incident. By operationalizing the theories in an electrical context and in a regional Swedish context, I hope to contribute to expanding the theories' practical applications. I also hope to use the theories' to improve electric power reliability.

To achieve these purposes I will need to study the current status of power reliability and current measures taken to prevent power outages. I will then examine what the region's approach to power reliability is and understand them in light of the two theories. This will enable one to order the information about power reliability approaches in a systematic manner. I will also analyse the approaches in order to find any patterns in how the actors manage this issue. This will explain why certain actors chose certain approaches and find the independent variable that causes that. The conclusion of that analysis can be used to explain approaches to power reliability in other contexts. Finally I will discuss how the current approaches affect power supply and how these theories can help a region improve their approaches to power reliability. This is important in order to identify the beneficial approaches and evaluate them for the benefit of future power supply.

The actual research questions are therefore:

- What are the current approaches actors take to prevent power outages and how do they work?
- Why do actors choose these approaches and what choosing-patterns form?
- How do these approaches and patterns affect the power supply?
- How can better approaches be evaluated and achieved?

A reliable power supply is important and these questions are important to answer in order to better ensure that. Answering them will enable us to have an ordered view on how approaches to power reliability are formed and the factors behind them and what the consequences of this is on a regions power supply.

My hypothesis is that actors are not too aware of any kind of systematic approach to a reliable power supply. From anecdotal evidence gathered at two workplaces working with planning, there is not much consideration to civil contingencies and it is not integrated in the planning work. The work does not rise above what is required by the law such as providing for delay dams for rainwater to prevent flooding. And it is not strange that some aspects are missed in times of ever increasing specialization.

There will be a difference in how the private sector and public sector manages the problem respectively because of their different organizational set up and motivating factors. Internal differences within each sector will depend on more idiosyncratic factors. I think the public actors are more aware of the theories because of their general work with risk, planning and so on. The utility companies are perhaps more interested in practical experience and measures tested through trial and error rather than peer reviewed measures.

Nonetheless I think many of the measures each actor has taken will contain many of the implications suggested by the theories. This is because the theories don’t provide radical new solutions but rather explains how certain solutions work and why they are effective. Therefore it shouldn't be surprising that the actors are already implementing some of them. The difference is that the theories provide a context and explanation for the measures.

With that said, there will be some aspects missed by the actors that the theories can fill. Organizations can sometimes get used to one type of measure while a theory provides a whole paradigm to work with. Therefore the theories will most likely be able to at least help evaluate future measures for a better power supply.

The result of this paper could be used to expand the theories to include non-accident disruptions to a complex system. Therefore they will be applicable albeit with some modifications.

3. Scope:

Civil contingencies is a very broad subject. This includes all important societal functions (ISF) from electricity to a working food supply chains to a functioning transportation system to working hospitals and schools. Within this broad range there is the technical infrastructure sector which includes electricity, water supply and disposal, electronic communications and telephony. Within this sector I chose to delimit the paper to be about electricity as it is the most important one of them. Without this the others would not function. The other ISFs and infrastructures will only be mentioned in their capacity to affect the power supply. The same goes for the threats to ISFs such as malfunction of the payment system, natural disasters, pandemics etc. These will be discussed in their capacity to disrupt or be disrupted by a power outage. Within this infrastructure I chose to focus on the preventative aspects as opposed to the mitigating and recovery aspects. Uninterrupted supply is a key indicator for measuring the quality of electricity.

I also chose to delimit the paper's scope geographically by focusing on Scania. A paper on all of Sweden would be too large to cover within the bounds of this paper. The region has a functioning regional grid which serves as a basis to work with. The municipality and county board are actors whose main operations play out in a regional context. The same goes for the municipal utility company Öresundskraft. The other utility company, EON, is national but maintains a regional division.

4. Method, methodology and material:

The paper will combine theory and empiricism. It will take part in current action plans and RVAs and other documents necessary to study an actor's approach to power outage prevention. This means one method will be literature study. It will use literature produced from public and private organizations. The literature will be analysed in the context of this paper's purpose and theoretic framework. Including this method will allow me to use the actors own documents to evaluate their approaches to power outage prevention. The documents will be procured by downloading them from the actors' websites or through requests to the relevant personnel. The main drawback of literature study is that it relies on second hand information. This problem is not alleviated by the fact that the texts to be studied (government reports & research papers) can be considered trustworthy and authoritative. Some of those texts rely on interviews and other subjective methods. Take for example the CCA report on county Risk and Capability evaluations. It was built upon the counties' own evaluations which pose a credibility issue. In other reports it holds interviews with stakeholders. It is readily admitted that one person can come to the conclusion that capability is "good" while another can evaluate the same organisations capabilities as "good but with some flaws" (MSB p. 30, 2011). But being a second hand source does not always affect credibility as sometimes the purpose of the paper is to get the interviewees perspective on for example the effects of power disruptions. In this case detailed information is acquired because of the competence of the interviewed person. Sometimes the reports merely suggest actions and measures for the future. Still it is important to be aware of where these second hand sources have to be seen in a critical light.

Interviews will be conducted with county & municipal officials, an official from a municipal power company, with EON, the CCA, Swedish Defence Force and LUCRAM which is the Lund University Centre for Risk Assessment and Management. The interviews will be semi-structured. This will allow me to acquire the necessary information but at the same time allow for flexibility and for the participants to give their view freely. The participants can give their perspective, go deep into a particularly interesting subject and give examples. It will be possible for me to pose follow up questions. I will also be able to add or subtract or change the questions in another interview. This will be necessary because of the different responsibility areas the interviewees will have. The problem with this is that I cannot compare the answers of the participants with each other. This will not be necessary since this isn't the purpose of the study. The interview guide will generally follow the structure of the paper. First I will pose a general question on the participants work and area of responsibility. Then I will continue to ask what measures are being taken to reduce the risk of disruptions, protect power supply, and how their approach impacts power reliability. I will also ask questions on whether they focus on the technical and organizational aspects of their measures.

The problem with interviews is that they are not representative. The interview is conducted with one person from one administrative department in one municipality/company. But the purpose is not to understand the opinions of the participants' institutions but rather to get in depth information about what measures are in place to strengthen reliability. Then the representativeness becomes less of an issue as long as the participants can give detailed information about their organization's contribution to power reliability. To get as much information as possible the participants were chosen to represent as wide a range of institutions as possible. Two participants come from a municipality, one from a municipal utility company, one from EON (a major utility actor in the region), one from the county board, one from LUCRAM, one from the armed forces and one from the CCA. Another problem is the subjectivity of the participant. The participant is part of an organization which binds him to it. It is therefore in the participants' interest to exaggerate the positive role of his organization in power reliability. So in answering questions regarding the organization's role, caution is advised. There are also technical aspects to look out for. To ensure that the transcription of what the participant has said is not dependent on my memory or speed of notation, the interview will be recorded using a cell phone. The fact that the participant is recorded though can impact in his/her openness to sharing and in the accurateness of the shared information. This can be reduced by asking simpler question at the beginning to gain the confidence of the participant. A cell phone lying on the table is also one of the less intrusive ways to register what has been said.

Interviews will not allow me to understand fully the culture of the interviewed organizations. This is a significant disadvantage if I want to evaluate if the organization's approach fits in with the HRT approach. For this I will have to use the answers they give me during the interviews and by reading their safety procedures and publications.

Finally observation will also be used to inspect current facilities and infrastructure. This is necessary to understand the structure and placement of key nodes in the system, security arrangements to be able to assess the extent of the measures.

The advantages of observation are that one gets a chance to inspect the actual infrastructure discussed in the paper. It also gives me a chance to describe in detail the settings that the infrastructure is placed in with regards to environment, surroundings, height, obstacles, activity in the area and nearness to people and so on. The information resulting from this is first-hand information. And because I will be observing inanimate objects my presence will not alter the observed objects. But there is the problem of subjectivity in the perception of the place and its description. There is no way around this but this is the cost of gaining information gained from human sources. This will be alleviated though by photographing at some installations such as transformer stations, poles and lines. There can also be problems with regards to access. Especially with regards to electrical installations as they are generally surrounded by fences. This means that I will have to make the observations from outside the actual installation. For obvious reasons I will not be able to examine the underground cables either. In general it can be considered a complementary method for information gathering to the other two methods.

5. Theory and Previous Research

Much of the previous research can be understood in the context of two overarching theories. These are the Normal Accidents Theory (NAT) and High Reliability Organization Theory (HRT). The interesting thing is that the research doesn’t refer to either NAT or HRT. But then again, the theories weren’t built to explain power reliability. Rather they dealt with nuclear power plant safety and air traffic control systems. The results from these case studied could then be used to build a theory with regards to all kinds of system failures and reliability. And some recommendations in the previous research *do* fit with what these theories would recommend. The NAT suggests that accidents are normal and can start out as fairly trivial. In a complex system these accidents are even likely and they can cascade through the system and spread which cause severe consequences. The more tightly coupled the system is, the faster the spread. Therefore good design, better safety features, less coupling and more maintenance is required to reduce the chances of an accident happening (Perrow, 1984).

The theory has been criticized for being ideologically motivated. Perrow, the author of the book first presenting the theory, suggests that the systems are accident prone because the “elites” wants them to be. There is also the problem of samples. The theory is built on a case study and general conclusions about system safety are drawn from that. Still the theory does give a possible framework to work within. If the theory is good then we can conclude that system design can improve to compensate for human ignorance, incompetence and error. Even if Perrow attributing the accident proneness to the “wrong” reasons, doesn’t make his implication that complex systems are accident prone less true. And the low sampling amount can be addressed by using the theory in other contexts to test if it holds out (Whitney, 2003).

HRT suggests that we not look too deeply into the specific accident. Although accidents are normal, they are but a symptom of the inherent weakness in organizations. There are certain high reliability organizations that manage accidents better than others though. These organizations shun the “culture of diminished expectations”. That means they think of smaller problems as early warnings instead of considering them to be a normalcy. Standards and procedures may be eroded because of decay or simply because it has yet to show any consequence. But high reliability organizations (HROs) on the other hand don’t “creep towards the edges” when it comes to safety. HROs always maintain a level of mindfulness (Weick et al, 1999).

High reliability organizing is characterized by five key principles that address both problem detection and management. First of all they are immersed in learning from failure. They use even near failures to learn about their strengths and weaknesses. Secondly they don’t simplify. They search for the root causes of failures and don’t stop at superficial explanations. Thirdly they are aware of their systems fragility and how an accident can spread throughout it. On the managing side they develop a capability to cope with the unexpected. They expect to expect the unexpected. Finally they use the expertise at their disposal. They build their decisions on good information provided by reliable experts. By adopting these routines and practicing them in a daily manner, HROs develop a high level of mindfulness and a strong safety culture (Weick et al, 1999).

HRT has been criticized though for being non-falsifiable. Its conclusions cannot with certainty be attributed to the achievement of a HRO. It is also hard to measure whether an organization is a HRO and how much of a HRO it is (Shrivastava et al, 2009). But HRT still provides valuable insight on institutional deficiencies which can lead to less reliability. Some of these insights are counter intuitive. From HRT we learn that there are fewer errors in air traffic during a high load than during a low one because air traffic controllers are more attentive then. Another is that, we might think that things are under control and pay less attention as long as something isn't happening. But we should not assume that, because unreliability remains invisible until it actually becomes disruptive (Weick et al, 1987).

As the theories were not intended for use in an electrical context they might require some modification, or at least that there is awareness of the problem in transplanting them into this context. When transferring the NAT's application to the electric grid you conclude that the grid has to become more flexible. And you have to become more decentralized in the electric grid to become more flexible. So far this is in tune with NAT's calling for less coupling. But more complexity (automation) is going to be needed in order to decentralize the electric grid. This is one contradiction that has to be considered. Moreover the NAT calls for better designs and safety measures. But in installing those to the electric system could render it more coupled and complex (Perrow, 1984).

The HRT is less problematic to transfer. Part of the reason is that it is a softer theory. It deals with organizations dealing with complex systems and not complex systems directly. Any organization could use the five characteristics of an HRO. The question is, would this help reduce power outages? The answer is a simple yes because undoubtedly some of those outages have been the result of human error. But the HRT does more than that. It actually fits very well for organizations that want to increase power reliability. Those organizations need to identify threats to said reliability and manage them. Three of the five characteristics of an HRO deal with identification of threats and two deal with management.

The different measures used in the region can be categorized as belonging to one or the other theory's approach. The line between them is not always clear-cut but rather it is a spectrum in which each measure can be placed. The more technical and design-related the more NAT the measure is. The more organizational and humanistic the more HRT the measure is.

The two theories can be summarized and compared using a table which lists the theories' foci and other factors. The result of the comparison is illustrated in table 1.

From this exposé of the theories I hope I have made it clear how they can help in assessing approaches to reliability in power supply.

	Natural Accidents Theory	High Reliability Theory
Approach	System failure	System reliability
Foci	Technical aspects	Human and organizational aspects
Emphasis	Better design, less complexity	Better organizations, more human control
Critique	Ideological, small sample	Non-falsifiable, hard to control

Table 1. A comparison of the two theories with regards to different aspects.

There have been several studies which point to the utter dependence of society on critical infrastructure and electricity in particular. De Bruijne & van Eeten, 2007 published one about the protection of critical infrastructure in an institutionally fragmented environment. Although the fragmented environment referred to in the paper is the privatization of infrastructure, this paper can still be particularly interesting in the Swedish context. In Sweden the CCA touts the responsibility principle which means each agency is responsible in a crisis what it is responsible for during normal times. This also creates institutional fragmentation which requires a lot of inter-sector cooperation. Inter-sector cooperation generates what the HRT calls "requisite variety". This means that when the co-operators look at a problem they see more than they would have done individually. Amin, 2001; published a study about self-healing systems which quickly identify malfunctions in the system and addresses them. His conclusion is that these systems will be necessary in the future as a more sensitive industry demands higher quality electricity and they will be more feasible because of better computation and more powerful sensing agents. The main problem of implementation is the depth of intelligent system reaction. But there are measures in place to improve robustness of the system such as a double layered software system. This is a prime example of a paper that in its conclusions support the conclusion drawn from the NAT. That better system designs are needed to prevent accidents in the future. The International Risk Governance Council (IRGC), 2006, published a very interesting report where they discussed the risks to critical infrastructures, their interconnectedness and respective dependences and general recommendations for policy improvements. They concluded that many of the major blackouts were caused by a small event, in line with the NAT explanation of accidents in complex systems. They also concluded in line with the NAT that the automated systems were inefficient in dealing with the problems. And a lack of awareness and pushing the systems to their limits aggravated the situation and so lent some support to HRT as well. The solutions they suggested could be found in both NAT (reduced capability and complexity, self-healing systems & micro-grids) and HRT (training in realistic simulations). Little, 2002, published one about improving the robustness, resilience and reliability of critical systems among them which is the electrical grid. The conclusion is that electric grids are a system within a system, and that more than better engineering and technology will be needed to improve it. There is the organizational and human aspect that needs to be taken into consideration.

There have also been Swedish governmental reports. One useful document was produced by studying the effects of the Sandy storm and bringing lessons home for application in outage prevention and mitigation (MSB, 2014c). The CCA published a study on the interdependence of different critical systems (MSB, 2009). In the study were many useful analytical tools such as dependence profiling and domino effects. The CCA published an action plan for the protection of critical infrastructure in 2014 which contains practical measures to be used to protect critical infrastructure (MSB, 2014a). In a regional context Region Skåne has published a report called "Risk och Sårbarhetsarbete" (Region Skåne, 2012) which is the Region's RVA. All the actors involved in Scania must produce RVAs. This includes the Region, the county board, the municipalities and the utility companies. In these they list threats to power supply and measures to prevent them. Another document "Strategi för Regional Samverkan vid Kris i Skåne" (Region Skåne, 2010), is a result of cooperation between the County Board, the Region, the Municipal Association Scania and Police authorities in Scania. It concerns the regional cooperation in case of crisis. The county board of Scania has published a document outlining a crisis management plan and responsibilities during a crisis (Länsstyrelsen i Skåne län, 2006). These can be studied in addition to the county board RVA to analyse their approach.

In conclusion, on the national level there are many papers, studies and reports on ensuring a safe power supply. But these often give general recommendations to all agencies, counties and municipalities in Sweden and concern all the phases. The regional reports mostly deal with risk identification and crisis management.

6. Results & Analysis:

6.1 Approaches to a reliable power supply by the regional Scanian actors

In this section we shall analyse the information gathered and the literature study and interviews to analyse what kind of approach the different actors take in order to prevent outages.

6.1.1 Approaches by the county board: identifying threats and crisis management

The most obvious way the county approaches this problem is through its Risk and Vulnerability Analysis. In an RVA one should identify risks to the region's well-being, describe the consequences of a risk occurring and the probability it has of occurring. With that they also describe measures taken to reduce the risk of a risk happening. In the county board's RVA, they mostly discuss the consequences of an outage. They only touch upon the probability of an outage happening. It focuses more on reserve power and directed power for prioritized activities. This can be interpreted as giving up on the idea of 100% reliability and instead focus on how restoration can be improved. In this regard the county board does not aspire to become a HRO. But when preparing for restoration measures, drills are very much incorporated as HRT would recommend (see table 1). But it is paradoxical because HRT per definition concerns itself with organizations that are high reliable meaning they are focusing on the problem not happening in the first place.

Identifying threats has a major part to play in dealing with power reliability. In the RVA there are some important threats such as import of power and centralization of production that are not mentioned. So although the RVA does list a lot of risks there are some that are missed. The county might have more information than what is published in the public RVA. But the document that was sent to the CCA did not mention these threats.

The power lines are where the disruption most often happens. The major threats identified to this are mostly related to natural disasters. Ice storms are identified because of the ices lingering effect. Solar storms are identified and discussed. The solar storm threat is discussed rather detailed with regards to consequences, probability and measures. Solar storms are relatively likely events. The average period for solar maximums is 11 years. Last time it affected power supply was in 2003. And Scania is more vulnerable for this kind of threat because its bedrock conducts electricity worse than other parts of the country. Early warning systems are being set up in cooperation with the Department of astrophysics in Lund. This is a rare instance of the county pointing to a technical measure to reduce and manage risk to the power supply. This approach falls within the NAT approach (Perrow, 1984).

Scania is identified as vulnerable to cyclones because of its long coast and flat landscape. Much preventative work is being done in this regard. Utility company are burying power lines, vulnerable trees are inventoried and forests weather proofed. Extreme rain condition was the scenario used for 2014’s RVA. To reduce power outage risk, an information campaign targeting ISFs and the public regarding placement of electronic equipment and reserve aggregates is suggested. When addressing these threats the county mentions technical measures again. In this case it is possible for the county to do that because it describes the measures taken by other actors. When these are taken out, only the informational and training measure remains. The training measure can be seen in a HRT context. The informational measure can sometimes be seen as that. It depends on the purpose of the information campaign. Campaigns designed to strengthen awareness of an organization’s weakness, threat gravity or system fragility is a measure recommended by the HRT. Informational campaigns whose aim is to inform actors about where to best place equipment and so on is not as clearly a HRT recommended approach (Weick et al, 1987).

One more threat that is identified against power supply is pandemics and other widespread diseases. Pandemics are mentioned to be a threat to many ISFs because of their impact on personnel who operate the ISFs. The county board RVA addresses the topic by conducting drills in case of epidemics and heat waves. Preventative drills were conducted in the region’s ports and airports. Police and customs authorities and the coast guard have conducted their own RVA and other measures intended to strengthen awareness of the problem. More imports from other countries have increased this risk. There are controls and tests being done to imported animals but there is pressure from the EU not to do this. The drills and RVAs are part and parcel of what the HRT implies is needed to become a HRO. The controls and tests to imported animals fall within a grey-zone. It is not a technical measures designed to reduce the electrical grid’s complexity nor is it a safety measure within the said grid. At best it leans towards falling within the HRT category because the theory’s implies that good procedures are needed (Länsstyrelsen Skåne, 2014, 140).

Other non-weather related threats are considered unlikely by the county. The risk analysis is quite right in that the disruptions that have happened in the past stemmed from extreme weather. But reliability is as we learn from HRT precisely the opposite to events; non-events. It is for these that one must be vigilant (Weick et al, 1987).

The county board chief has regular meetings with the chairman of the regional council, the president of EON utility company in Sweden, representatives from the emergency services and the Defence Forces. The purpose of the meetings is to identify strategic questions of safety and improve cooperation and coordination (Länsstyrelsen Skåne, 2008, 8).

The county board has also published a document called ”Strategy for regional cooperation during crisis in Scania”. In this responsibilities of different actors are outlines during all phases of the crisis at the operative level and strategic level. Here all actors have a responsibility to follow on-going developments in the outside world and report the results at the regular meeting. It is then decided what information is important enough to be forwarded to other actors. This cooperation council is also the coordinating body if an actor wants to disseminate a so called "important message to the public". This makes sure the other actors can contribute to the information about to be disseminated, and it makes sure that they know what has been disseminated so that the public receives concurrent information. This kind of cooperation strengthens all the partners' requisite variety and enhances their ability to identify risks and manage them (Weick et al, 1987).

To manage the risks, the county board has a procedure that is flexible enough to expect the unexpected but might lack in the expert pool. They have a crisis management group that can be expanded as there is need for it. In later stages they can call in representatives of outside organizations. This is part of the five characteristics of a HRO, that they expect the unexpected and use experts to make informed decisions (Weick et al, 1987).

By the very nature of their approach to power disruptions the county works within a HRT paradigm. The tool they use, the RVA, invites to those kinds of measures. The county identifies risks which is in itself a HRT approach. It then presents measures that are taken or will be taken to reduce and manage those risks. These measures are usually about improving training, drills, cooperation and information, all of which more or less fit in with an HRT approach to improving system reliability (see table 1). Some risks are missed because of the RVA not being detailed enough or because of lack of resources. The final RVA produced is thereby formed by practical necessities. The other way they work to manage risk is through the crisis management group, which essentially is an organization whose sole purpose is to manage imminent and on-going threats and crises. In the rare instances of presenting solutions that could be said to fit in with NAT, they are usually those of another actor which the county has decided to present in their RVA.

6.1.2 Approaches by the region: security culture & knowledge

The Region which is a separate entity from the county board doesn't deal with power supply directly. They deal mainly with healthcare and transportation. But they still conduct RVA within the context of their areas of responsibility. They also have a responsibility to sustain functionality during crises and maintaining power is crucial for that. The Region has approached this mainly by organizational reforms.

The method used by the Region is called the Multidimensional Activities Analysis which has been developed by researchers at Lund and Malmö University. This means that representatives of different departments gather under seminary like forms and discuss the issue at hand to later forward the results to relevant decision making body (Region Skåne, 2012). A cross sectorial cooperation is needed to diffuse knowledge and save resources. This intersectionality also strengthens the Region's requisite variety in understanding risks and managing them. Requisite variety is an important part of the HRT. Organizations must have the ability to detect threats where they weren't even considered. And they must expect threats from unexpected sources. One way of doing this is through looking at a problem with different eyes.

An outspoken goal for the Region is to improve their "security culture". This means that the organization will continuously search and pay attention to risks and manage them. It means to make it into a routine to incorporate risk and vulnerability work in the daily work. The goal is to do this without fixating the routines to search for the same risks as usual. The goal is to discover new types of risks that can develop as a result of changes to the outside world. HROs relationship with security culture is a symbiotic one. HROs need to develop a security culture in order to become HROs and part of the purpose of being an HRO is to achieve an entrenched security culture (Weick et al, 1987).

The Region couples this with training programs and awareness increasing measures. There is also a call for more training and continuous exercises at all levels. The Region has many parallel processes in their security work. Besides the RVA they work with environmental safety, ergonomic safety and informational safety. By identifying and reducing risks in those areas, risk is reduced in their main functions too (Region Skåne, 2012).

The Region has identified important objects and various threats in their area of responsibility. They have also conducted major scenarios to prepare for some of the threats. In 2008 the scenario was about a power outage leading to the failure of IT systems. The result for the first phase of the crisis was “good capabilities with some flaws”. The solution has been more knowledge and research but the need to maintain a basic security level is also stressed (Region Skåne, 2012). The purpose of this knowledge is to understand what the appropriate measures are. The purpose is not to increase awareness. Therefore the knowledge purported is not one that strengthens an organization from a HRT perspective, even if this knowledge can be beneficial. The need for a basic security level is what is needed when seeing the issue from a NAT perspective (Perrow, 1984).

They don’t have a clear cut HRT approach. While working with culture and reducing risk in all areas is HRT because of its encompassing nature, the informational measures are HRT only if their purpose is to strengthen awareness of the organization and the system. Other measures that are non-HRT are the general need for more research on appropriate measures and the need for a basic security level. There is a conspicuous absence of technical measures though. Since one of their main responsibilities is functioning transportation this might seem strange. A functioning transportation system is needed to supply the power plants with fuel. This can have to do with grants from the state mostly encouraging measures of the organizational kind (Interview with Jan-Olof Olsson & Omar Harrami at MSB 9/4/16).

6.1.3 Approaches by the municipality: coordination & cooperation

The municipality’s responsibility when it comes to power supply is to coordinate the recovery from outage. It has some responsibility to prevent an outage. It does this mainly through the “Styrel” cooperation. With this, electricity can be rerouted if there is a demand increase or a sudden supply decrease. Rerouting power is a measure involving the power grid and is therefore a technical measure. It is a safety feature installed to prevent errors as the NAT would describe it (see table 1) (Perrow, 1984).

The interviewed person admitted though that the preparations are worse in case the whole municipality is taken out. For now, the municipality hasn't gone through any situations where the capabilities were put to the test. But there are lectures, scenarios and drills conducted to train for crises. They do work in a long-term manner by incorporating preventative measures when building new areas. The municipality also cooperates with operators of municipal infrastructure such as the municipal power utility company Öresundskraft. The main responsibility of a reliable power supply lies on the utility company. Cooperation is close with neighbouring municipalities in what is known as the "Family of Helsingborg".

They cooperate with the association of Swedish municipalities and counties and read their reports and that of the CCA's. That is considered part of the municipality's intelligence gathering. They don't consider the recommendations of the reports as binding because they are just recommendations. But they adopt ones considered relevant for them. There is a crisis plan that outlines how to organize the work during a crisis but it is not detailed in that it discusses different threats and responses. Doing that would be above the capacity of the municipality (Interview with Monica Eriksson at Helsingborg municipality 1/4/16).

The municipality is aware of the CCA's dependence analysis which should be completed by the year 2020. The municipality hasn't begun their analysis yet because of recent personnel turnover. The municipality in their work identify key objects that need to be prioritized, categorize them according to importance and forwards it to the county board.

So to prevent smaller problems of cascading the municipality uses the Styrel rerouting program. But when it comes to the whole issue of a larger power outage the measures are lectures, drills and cooperation. The purpose of the lectures is to increase awareness of municipal vulnerability within the organization. The drill's purpose is to strengthen personnel competence which in turn strengthens their reliability. The cooperation is done out of necessity because the municipality doesn't own any power facilities. But an unintended consequence is that the requisite variety of both the utility company and the municipality increases. By not doing the dependence analysis the municipality risks missing some risks and vulnerabilities which reduces its reliability as an organization. But when they identify and categorize objects they do it a systematic manner, not missing even trivial ones such as parking garages. This way of approach is very much encouraged by the HRT. Intelligence gathering is not something implicated directly by the HRT but doing intelligence gathering helps an organization learn and evolve which is very much the heart of HRT (Weick et al, 1987).

6.1.4 Approached by the utility companies: physical and technical security

During production of electric power, the plants need command and control systems, delivery of said systems parts and other reserve parts, telecommunications and qualified personnel. The control systems are automated but have the ability to lend itself to manual control. There has been a general trend in power plants to reduce personnel in order to rationalize operations. Although this can be economically sound during normal times, it increases vulnerability by reducing redundancy in personnel. If some of the staff were unable to come to work, operations would begin to suffer. On the national level, most major plants are staffed 24h a day. But minor plants on the other hand may only have staff during office hours. These approaches go contrary to the conclusions of both NAT and HRT. On the regional level the situation is better though.

To reduce the risk of natural accidents and technical errors the operations centres of EON (the major power grid operator in Scania) and Öresundskraft (a municipal utility company) are staffed 24h a day. Additionally there are field personnel that can take care of simultaneous errors in the grid. EON conducts routine maintenances of lines and facilities. The number of technical errors has been decreasing even though the number of sensitive components has been increasing. This can interpreted to both support and contradict the conclusions of NAT. On the one hand, better maintenance should decrease the errors in a system, but on the other hand installing more sensitive and complex components should increase them. A way of reconciling this is through ascribing a stronger effect to maintenance than to component sensitivity.

EON identifies risks and vulnerabilities in their own internal RVAs. They then share some of this with other actors such as the county board, the CCA and Svenska Kraftnät. Because EON has classified its RVA it is hard to know exactly how they do. But from an interview with an EON Power Grids employee I learned that the major threats to distribution as they see it are weather related. It can either be a storm, wet snow or lightning. Other problems are facilities being run over or technical errors. They do identify sabotage as a potential threat but that it is not so usual. One threat that is different from what the public sector identifies is measurement errors. Problems here could cause production to shut down. Measurement problems can arise from either technical errors or cyber-attacks. There have even been attempts at attacking the IT-system but they haven’t been successful. A common denominator of the identified threats is that they all threaten the physical component of power supply. The measures EON takes to protecting themselves and prevent outages also have to do mainly with physical protection.

To protect themselves against sabotage, routing stations are fenced and alarmed. They also have surveillance with CCTV, guard patrols and cooperation with law enforcement (Interview with Johan Aspegren at EON, 13/4/16) (Interview with Öresundskraft official 19/04/16). This kind of cooperation should perhaps be interpreted as a measure designed to strengthen the physical security of the grid. Therefore even if it is a non-technical measure it serves a technical purpose.

The electric facilities of both EON and Öresundskraft have physical barriers for preventing trespassing. There are fences topped with barbed wire and behind the first fence is sometimes another electric fence. The facilities being protected this way are the substations which are of intermediate importance. There are thousands of substations in Scania making them plenty. Among them are around a hundred feeding stations from the regional grid to the local grid. Some are located relatively central and some on the countryside. The central ones are usually more protected. One substation in Bjuv has a damaged fence while one in central Helsingborg has two layers of fencing. Although the actual substations are fenced, the surrounding area is easy to access.

The level of security in plants is being increased by making fences higher, improving alarm systems and CCTV surveillance of facilities. Especially important facilities can apply for funding for additional security measures from the Svenska Kraftnät state utility company. These are critical to protect and therefore receive more protection. These are all technical measures that can be interpreted as fitting in more with the conclusions of the NAT, even if the NAT does not outright call for these particular measures (Interview with Jan-Olof Olsson at MSB 9/4/16). In fact NAT suggest internal measures on the actual system to protect it from failing from within. But the spirit of NAT is one of technical safety features (see table 1). Therefore external measures are just as valid (Perrow, 1984).

The power lines are not as important to the companies because destroying one would cause minimal damage. But on the other hand they aren't protected by anything in the countryside making them vulnerable. The lines of importance are the core lines transporting electricity at 400kV. There are four such lines importing electricity to Scania from northern Sweden and one is being built underground. To Denmark there are three lines. Protection of these is not addressed by the county board, the region, the utility companies or the municipality even though most power in Scania is imported through these lines. This has to do with the fact that these lines are owned and operated by Svenska Kraftnät (the state utility company that supervises the core transmission grid). So the approaches that the actors take are not one where the most important issue is addressed. But the approaches rather follows the principle of area responsibility; i.e. that all actors are only responsible for their own activity (Interview with Anna Rinne at MSB 7/4/16).

Figure 4. Example of the fencing around substations.

EON and Öresundskraft maintain redundancy in their grid. The core and regional grids are built that way so that as few people as possible are affected. Larger cities, towns, stations, facilities and nodes in Scania have two lines supplying them. In Malmö the nodes have three supply lines. New lines are being built to further strengthen redundancy. The risks now lie in individual components/poles in the system not working. So therefore many of the local lines are buried below ground. New lines are almost always built that way. Older lines are slowly being buried. This increases the risk of non-weather related events such as digging into a power cable. But the risk of mass outages and mass failure is reduced. The purpose of the NAT is to prevent major incidents. By protecting the power lines against the weather you prevent many small failures from happening at the same time or stop a minor failure from cascading through the system and thereby also prevent a major failure (Perrow, 1984).

Besides the technical measures EON does cooperate with the county board, research institutions, the CCA, Svenska Kraftnät, police authorities and the Swedish Security Services. They follow on-going developments in the outside world. The personnel are constantly trained, and because of the company's size they have a large personnel pool at their disposal (Interview with Johan Aspegren at EON, 13/4/16).

Other measures they have taken to reduce risk are to order custom-made prognoses from the Swedish Meteorological and Hydrological Institute (SMHI). This is to be able to prepare for any weather related disruptions (Länsstyrelsen Skåne, 2006). Early warning is essential to prevent and mitigate outages. This was one of the lessons learned from the Sandy storm that hit the United States in late 2012. With earlier preparations more information could have been disseminated to the public and more reserve fuel and parts could have been stocked. Electrical equipment could have been removed from lower levels thereby preventing outages and personnel could have been sent out pre-emptively to guard important facilities (MSB, 2014c). To detect a looming threat and having an early warning you need technical instruments. But the result that the early warning produces is a better functioning and more reliable organization. The organization can be put on high alert. HRT suggests that organizations always be flexible and on high alert or mindfulness as the theory calls it. The problem of applying that in real life is that most often it is hard to maintain such a high level of mindfulness for a longer period of time. But HRT says that a HRO is one where the standards are not decaying or reverting to less stringent but acceptable procedures even if it is hard. By having an early warning system the organization can combine a technical measure to achieve the results produced from having a high level of mindfulness (Weick et al, 1999).

Öresundskraft has a plant located on the outskirts of the city. That plant produces 125 GWh per year. This is enough to power 40 000 apartments. The plant receives its fuel mainly from local waste and so has a close source of fuel. It does import 20 % of it from England. They are aware of the importance, weaknesses and vulnerabilities of the plant. That is why they have reserve waste that could power the plant for 5 days in case deliveries would stop. Customers delivering waste have to give notice in case there will be a delay or temporary halt of delivery. Its location on the countryside makes it harder to protect against sabotage. But it is has many security measures implemented. It is fenced with fences that are topped with barbed wire. There is camera surveillance by the gates and inside the perimeter. There are also security patrols. They have had break-ins but those were to steal scrap metal in the perimeter (Interview with Öresundskraft official 19/04/16).

A general threat to power production according to the companies is disruption of communications. Communications are important for monitoring and controlling the system. To counter this, safe communications have been installed in the control rooms. And the RAKEL radio system is being introduced in the utility companies. The advantage of Rakel is that it is designed to withstand extreme conditions such as bad weather, extreme loads and power outages (Svenska Kraftnät, 2013).

The utility companies put the emphasis on threats to the physical production and transportation of power. The measures they take are also technical measures designed to enhance the protection of production and transportation facilities. Some of these are external

Figure 5. Examples of security measures in front of a power plant; fencing topped with barbed wire and patrolling by a security company.

such as surveillance and fencing and some are internal such as grid maintenance, and robust control systems. Some measures can be said to be organizational. Maintaining a fuel depot to keep the plant running and the ability to put the organization on high alert are examples of such measures. The conclusion though points overwhelmingly to approaching power reliability from a NAT perspective where preventing failure is a top priority (Perrow, 1984).

6.2 The region's approach as a whole to power reliability

The actors in the power business are prime candidates to fit it with organizations that need to be high reliable ones. And the electric grid is a prime candidate to be considered a complex system. So do the organizations and the grid in Scania make use of the conclusions learned from the two theories?

6.2.1 The region and the HRT approach

In their report the CCA concluded that many municipalities have trouble identifying long dependency chains. That is, they can identify immediate dependencies but it gets harder, the further one reach backwards. The first step of risk management is to identify it. But by going to the beginning of a dependency chain you search for the root cause of the dependency. This type of reasoning is one of the five characteristics of an HRO. The public actors today sometimes lack this kind of reasoning. The private organizations evaluate more closely the effects that new systems and procedures have on the system.

Another characteristic is to learn about the strengths and weaknesses of the organization. This means controlling risks emerging from within the organization. Today the organizations conduct internal RVAs. Local RVAs could be subject to home blindness and sclerosis of thought. And by focusing on local risks there could be risks that are discounted. Risks do not consider any municipal borders and they easily spread across them. Therefore internal RVAs are not optimal to learn about the weaknesses of the organization. None of the actors today have external RVAs being done.

But there is another way to learn about strengths and weaknesses. It is by learning from accidents and near accidents (Weick et al, 1987). Here the organizations do well. They have a routine for input and feedback. In the aftermath of Gudrun EON buried 30 000 km of power lines. This is a general trend throughout Sweden. There were also reports written to estimate the damage and so on. But to be an ideal HRO preventative work is needed. Risks need to be countered before they happen and near misses need to be reckoned as failures that have to be addressed immediately. One positive aspect of near misses is that they could work as a basis for a drill. Monica from Helsingborg said that they've never experienced any actual crisis. But there surely have been incidents were minor accident almost could have cascaded throughout the system. Using those as an opportunity to exercise crisis management is a sign of becoming an HRO. Most organizations do conduct real time drills. But an upside to using minor incidents and near misses is that if the minor incident does spread, then the crisis management is already under way. And when knowing that the drill could become a real scenario, it becomes much more realistic.

HRO are aware of their systems' fragility and how an accident can spread throughout it (Weick et al, 1987). All of the organizations examined have conducted consequence analyses and are aware of the importance of critical infrastructure protection. In assessing a risk though, more emphasis needs to be put on the probability aspects to fully grasp the risk level. This means that less frequent but bigger incidents should be preferable to more frequent but lesser incidents. The probabilities needs to be better understood and estimated to make the assessment more accurate. Today they are based on previous experience of the phenomena which is an example of the practical approach. But being a HRO means being proactive and considering unexpected factors that can increase the risks of an incident. The awareness of how the system is tightly coupled is good. The employee at EON said that they have to measure the power needed, produce it and distribute it for every second of the year. An employee at LUCRAM said that errors in the core grid could spread within milliseconds. Therefore the management and control of that grid is automated. The regional grids are not so tightly coupled as the core grid, but they are still highly automated. The local grid is managed manually because the reaction speeds needed are at a human level. By not automating one can retain the human judgement sometimes needed. This makes them less accident prone (Perrow, 1984).

Many of the measures suggested in the various documents aim at increasing awareness and spreading knowledge about critical infrastructure and crisis management. The public sector emphasised awareness more than the companies. But the companies were more confident in the robustness of the system than the public sector. But this does not mean that the companies' aren't aware of the need for constant improvement. The awareness of the system's vulnerabilities is generally good in both sectors.

On the managing side HROs use the expertise at their disposal. They build their decisions on good information provided by reliable experts (Weick et al, 1987). Here the companies are excelling. Especially the larger ones have the resources to call in personnel and material at a short notice. The public sector can call in consultant to specialized positions but generally don't have a large expert pool to draw from at a short notice.

Finally HROs develop a capability to cope with the unexpected. They expect to expect the unexpected (Weick et al, 1987). The county board and municipality have a crisis management group to cope with the unexpected. The Region wants to achieve this ability through their security culture. An example of an unexpected threat in Scania is antagonistic attacks. There have only been minor sabotage acts targeting the grid in Sweden (Holmgren et al, 2007). But still, it has been discounted in by the public actors. In this regard the actors do have some of this characteristic but ignore it in another context.

6.2.2 The region and the NAT: error proneness and complexity

There are two stages to power supply; production and distribution. When it comes to production the plants are still prone to accidents. One of Öresundskraft's plants was forced to shut down once because of a technical error. This error was an example of the simultaneous failures that can happen to a complex system and of how practical measures aren't enough. First the Uninterruptable Power Supply (UPS) unit failed. This unit is not supposed to fail. This caused parts of the control system to be taken out. This led to heat generation in the turbine which damaged it. It didn't work when they tried to manually shut it down. This happened even though there had been checks done to the manual shutoff lever. Finally they had to cut the connection from the nearby transformer station (Interview with Öresundskraft official 19/04/16). This is an example of accidents combining to create larger incidents than the original one could have caused (Perrow, 1984).

In the daily work no one noticed that the UPS was damaged during its transportation to Sweden. Likewise no one noticed that the manual shutoff lever wouldn't work in for in an actual situation even as it was being tested in drills. With a systematic approach perhaps the UPS would not be considered a 100% uninterruptible and the tests of the lever would not be assumed to be a 100% correct. The practical approach is cost effective. If something works 99% of the time the practical logic says that making it a 100% effective is not worth the costs. But when it comes to power supply a practical approach is not enough because of the issues' sensitivity.

The incident was also aggravated by relying too much on automation. When the automated system failed, the personnel had to step in. That in itself is usual and perhaps even acceptable if the personnel are prepared for such an event. But the UPS and the control system were supposed to be uninterruptible. This can lead an organization to rely less on personnel improvisation, skill and competence. When the system does fail, the personnel can't step in to resolve it. This highly automated and tightly coupled system is anathema to the NAT. And the practical approach is anathema to the HRT. And we have seen that the current approaches of the actors can lead to incidents. Therefore the production process is still error prone.

Another one of Öresundskraft's plants is located relatively close to the city centre. It is located near major transportation roads. This could pose a danger because of the traffic accident risks. A truck leaking dangerous goods could force plant workers to stay home. The actual plant faces the street and so it is not surrounded by any fence. But there is a courtyard to the plant surrounded by a fence topped with barbed wire. Although these risks are not internal as those the NAT discusses, they still can cause interruptions to the system. To transplant the NAT to an electrical context one has to take into consideration external factors contributing to a disruption. Not resolving external threats would make the system more prone to accidents.

It is in the distribution process were most of accidents has occurred. And when it comes to distribution the problem is almost always a failure in one of the nodes in the power grid network. So although HRT is important for preventing human errors, the way to stop major outages is through adopting the NAT. In the RVA the county identified some current trends in this regard. The weather and tree proofing of the power grid was one such example. Here we can see that the solutions lean towards better design and implementation (Perrow, 1984).

EON has also installed more sensitive component in order to be able to detect variations, fluctuations and anomalies. The NAT teaches us that the more complex the system is, the more prone it is to accidents. This is contradicted by the fact that they have installed more sensitive components but still experienced fewer technical errors. This can be partially explained by the fact that errors and accidents are non-events. That means they won't show up until they actually show up. Therefore the risks associated with the new components can still be hidden. Even if the contradiction is not explained in a fully satisfactory manner we can still learn from the conclusions of NAT. The only sure way to reduce technical errors is still to reduce the complexity of the system. The fewer nodes, connections and sensitivity the less the risk of error there is. So in this regard the regional grid is moving towards more complexity and more proneness to error. To mitigate that they also do routine maintenance which helps reduce errors (Perrow, 1984).

Malmö is being developed to be like an island with power self-sufficiency in what are called micro-grids. By being isolated errors in the larger system won't affect it. At the same time there is the possibility of connecting it to the regional grid in case of need (Svenska Kraftnät, 2013). In Scania in general there is a development to even more decentralized production. Through local production one can drastically reduce the number of components without centralizing distribution. Local production would eliminate the need for the long transport lines and the numerous substations thereby making the system less complex and less prone to accidents. Super-local production at the household level would have even more of this. If the houses were solar powered there would almost be no need of any transportation and no need for any fuels. It would be the ultimate decentralization of power production which would make the system less complex and less error prone

Figure 6. Example of sensitive parts being protected by a concrete casing.

(Perrow, 1984). This is an on-going process to the Scanian grid. New facilities are small scale and more and more small actors are getting involved in the market. Some are being installed in private houses thereby eliminating the distribution process (Länsstyrelsen Skåne, 2013) (Interview with Jan-Olof Olsson at MSB 9/4/16).

Redundancy is another way of strengthening reliability. Today the regional network is built up like a spider web. If one node or line is taken out the target can be supplied from another one. But why do outages still occur. The answer is that all lines supplying a target are taken out. Besides storms or coordinated attacks, concordant technical errors can work together to take out important nodes and cause major outages. The errors can be because of low maintenance or human error. The companies seem to work with this by having routines maintenance schedules and training programs.

The most important components in substations are today encased in concrete casings. Even the lonely power lines are alarmed as to message a control room in case of error. It is unlikely that errors will spring from external factors (Interview with Johan Aspegren at EON, 13/4/16). Most physical protection today is designed to keep trespassers out. But a much more likely source of sabotage is actually the unintended one. It can be caused by a traffic accident, a car or truck running into a facility or substation for example (Svenska Kraftnät, 2013). But overall the system is not prone to interruptions caused by humans whether intended or unintended.

Internally the system can crash because of power fluctuations. And there are no incentives for an individual company to develop its own buffer capacity which would be able to handle demand fluctuations better. This has partly to do with the fragmentation of the electric market. So the regional grid is in this regard vulnerable to errors and accidents stemming from demand spikes (Perrow, 1984) (Interview with Henrik Tehler at LUCRAM, 13/4/16).

6.3 Patterns in approaches to power reliability

When interviewing the Lund University Centre for Risk Assessment and Management (LUCRAM) they said that they haven’t found anything that could point to a systematic and theoretical approach being used with regards to power reliability. From my interviews with the actors involved I come to the same conclusion. That means that although some or many of the actors' methods could be seen as belonging to one theory or the other the reality is that it is the theory that fits in with the actor's measures. Or to put it in another way, the actors implement the implications of NAT and HRT without being aware of them. This type of approach can be called the practical approach. This is where measures are thought of, implemented and evaluated separately and without a theoretic context. It also means that as long as something works then it is good. A small risk of interruption is acceptable because eliminating the risk would be too costly. This will have a profound impact on the actual power reliability. There is a difference when researching and solving a problem from a theoretical perspective and a practical one. A theoretic framework orders the facts and the phenomena can be explained by as few variables as possible. With this fact regime, new risks can be predicted. Working with a trial and error perspective can give a practical solution to an urgent problem but doesn't give a long term solution to risk management. There is now way of learning about the underlying factor that causes a certain type of error for example.

The reason for choosing the practical approach is that it is cheaper than scientific research. The public sector is hard pressed for resources and the private sector can still achieve profit without needing to adopt scientific style approaches to reliability. Therefore all actors share in the practical aspects of power reliability. But the different actors rely to different degrees on it. The municipality's and region's approach aren't that large to begin with. Therefore they would benefit the most from a practical touch and go approach. The county board and EON as larger actors have more systematics and thoroughness in their approaches. From how they handle risks one can conclude that they are the most thorough when it comes to evaluating the consequences of both risks and measures.

Another pattern that can be discerned is the use of respective theory. The public organizations (the county board, the Region and the municipality) usually suggest solutions in line with what the HRT has to offer. This can be explained in two ways. First of all, the organizational set up, responsibilities and authority causes the public organizations to converge to HRT.

For example, the most that the municipality *can* do is to coordinate efforts with other actors. They don't have the resources and perhaps more importantly not the authority to invest in any physical measures. The same goes for the other public organizations. Their responsibility is a geographical one where they are responsible for all sectors in their geographical area. This means that they can't focus too much on power reliability even if it is one of the most important functions. So generally the public defers responsibility to the private sector and the utility companies because they own the physical infrastructure.

Second of all the State itself funds and encourages organizational measures for public organizations. The 2:4 crisis fund that has been set up by the government gives public organizations funding primarily to activities such as training programs, drills, lectures and other awareness measures (Interview with Amanda Eldeland at the County board of Scania, 05/04/16).

But even within the public organizations there were different approaches. The county board focused much on the RVA document. The Region focused on their security culture and level of knowledge. The municipality was very heavily involved in cooperation with the municipalities' association, neighbouring municipalities, the county board and the municipal utility company. These differences can be explained by the organizations' respective areas of responsibility. The county board receives the RVAs of all the municipalities in their geographical area and assesses the risks and vulnerabilities of the whole region. Focusing on the RVA is the most cost effective way for the county board to manage risk. The crisis management group that is set up is mandated by law. But its flexibility stems from the county board itself which could be related to competent management, awareness of importance of flexibility or other idiosyncratic factors. The region deals very much with transportation and health care where safety and security long has been a high priority. This has produced a culture of security which can be expanded on. The municipality as mentioned can't do much besides cooperate with the relevant actors and coordinate the actors in case of a crisis.

For the private sector there are the opposite incentives. Their organizational set up, responsibilities and resources causes them to converge to NAT type approaches.

The utility companies are positively and negatively incentivized to work with power reliability. There are strict rules demanding that a power outage shouldn't last longer than 24h. In some instances the maximum allowed time for an outage is 2 hours. Failure to meet these can lead to compensatory damages being paid out. The positive incentive is profit. If there is no power delivery there can be no revenue. So they need to make sure that power reaches their customers. Second of all they are the owners of the facilities and are responsibility for both power production and transportation which means that they and are responsible for their respective robustness LUCRAM (Interview with Henrik Tehler at LUCRAM, 13/4/16).

The companies are profit driven and have a smaller area of responsibility compared to the public organizations. That gives them more resources to invest, and it enables them to make substantial investments into power reliability. And the investments can go beyond merely organizational ones.

Finally the companies can apply for funds from Svenska Kraftnät. And the funds that they give out are mostly for physical investments. Even if that is the case, the companies in Scania have not applied for those funds so far. There are stringent conditions put on the projects that can be applied for which might explain why the companies hasn't applies for them (Interview with Johan Aspegren, 13/4/16) (Interview with Öresundskraft official, 19/04/16).

For the companies the measures have been very similar. This conformity can be interpreted as being caused by the same motivating force; negative and positive incentives. These incentives leads the companies to approach the issue in the most practical and cost effective way which then result in similar measures for both companies.

A pattern in the region's approach is the fragmentation of the actors and subsequently the fragmentation of the measures. Each actor works within their own area of responsibility. This stems from the CCA notion of area responsibility and a lack of intensive coordination. The county board has a geographical area responsibility so there is some intelligence gathering on what is happening in the region as a whole. EON as a large actor cooperates with the county so there is some cross-actor, cross-sectorial cooperation. But the cooperation is within specific contexts and not in the approaches taken by each actor. In a paradoxical observation the municipality has the deepest kinds of cooperation. This is even tough they are a medium sized player with dispersed responsibilities. The reason perhaps is that they are the kind of organization most in need for other actor's expertise and help. Large actors can afford to have shallow intersectional cooperation while medium sized actors which are more fragmented need the deepest ones.

A final observation when it comes to evaluating the approaches taken by the actors is that some of the measures and approaches are within a theoretic grey area. They are not approaches that fit in purely with the narrative of either theory. Examples of those are informational campaigns aiming at spreading knowledge of practical tips and animal tests and controls. These can't be interpreted as belonging to either theory although they can be said to lean more to one than the other. The reason that the observed facts don't always fit in is that the actors don't consider how measures are related to each other. This is part of the practical usage of measures and the actors' unawareness of theoretical approaches to power reliability.

6.4 Consequences of the current approaches on the power reliability

As mentioned earlier, the un-theoretical approach to power reliability affects the handling of this issue. It leads to certain parts of power reliability being missed. The unsystematic approach to power reliability has led the actors to miss the greatest threat to Scanian power supply.

Most power in Scania comes from the outside. This means that a disruption of the distribution even outside Scania can affect supply inside Scania. Disruptions happening in power plants beyond Scanian borders can have profound effect in the regions supply. In addition to production problems, vulnerability arises from the fact that the power is being transported thousands of kilometres from the north. Every kilometre represents more vulnerability and risk (Perrow, 1984).

We saw that the grid is still error prone and that the organizations are not completely reliable. If one were to see the issue from a NAT perspective one would need to take a look at the whole system and then strengthen the weakest point or divide it into self-sufficient subsystems. But this still doesn't resolve the underlying issue. From a HRT perspective one would look at the whole threat picture. When that is done the HRT would imply that the risk must be regarded as possible even if it miniscule and one would have to go to the root of the problem. Then the NAT could again help assess the technical measures to reduce this risk.

There are some important conclusions missed. An example in this case is the implication that even small risks need to be accounted for and that solutions have to be thorough. By using the NAT and HRT we can discover new risks that span longer time horizons and that are cross sectorial. They can then be addressed and technical solutions can be evaluated in a systematic and thorough manner. By using practical approaches all these aspects are missed.

Not identifying centralization as a threat is caused partly because of lack of theoretic framework and partly because of the principle of area responsibility. This leads to actors working on risks to their immediate activity and not identifying longer chains of dependency. In 2010, 76% of the power produced in Scania and 22% of the power used came from combined heat and power plants scattered near 5 of the larger cities and towns (Malmö, Lund, Helsingborg, Hässleholm and Kristianstad). So although centralization poses a risk to regional power supply, the production of power is fragmented enough for each actor to not recognize the threat (De Bruijne & van Eeten, 2007). When the actors are fragmented the measures will be fragmented. This will lead to missed synergy effects and mismatches in approaches used. This can be reduced by better and more intense cooperation.

The exception that proves the rule is the power grid. The last step for electricity to reach the end consumer is distribution. For this the power is dependent on the electric grid and other physical infrastructure such as transformer stations and electric substations and power lines. In Scania the grid operation is not so fragmented. The major grid operator is EON. They have thousands of kilometres of lines, thousands of substations and about a hundred feeding stations. As the outcome of an accident will be their responsibility they have invested a lot to the grids robustness. They have buried many lines, weather proofed others and set up alarm systems in case a line is disrupted and so on. This reduces the risk of weather based and antagonistic threats but creates more risk in the form of increased reliance on IT. This new risk is identified thereby diverging from the standard practical approach of not identifying a risk systematically or in longer chains. But with their current approach they regard their IT system as fairly robust because it has withstood previous attacks. This is an example of their practical approach to reliability. But practical approaches have serious consequences when not conducted systematically. This is exemplified by the malfunction that happened to Öresundskraft’s power plant.

A positive aspect of the practical approach is its cost effectiveness. If it weren’t cost effective it wouldn’t have been used in such a widespread manner. The practical approach accounts for most of the problems facing a reliable supply. Identifying and solving every possible threat would cost too much. It is not worth it for each individual actor. A reliable power supply is a common good which is sets it up to be an example of the tragedy of the commons. The root problem then, can be attributed to the nature of the coveted result in addition to the practical approach.

6.5 Theoretic foundations for a better power reliability

In what ways could these theories be used to evaluate the proposed measures to improve reliability? And what is preventing the region from completely securing the power supply or at least working to address the issue in a systematic manner?

The main obstacle to investments in reliability is economy. Companies are hard pressed to turn a profit and without incentives, it would be hard to convince them to invest. Robustness and reliability depends on the ambition of the actors. Although the NAT and HRT do not address the issue of financing, it can be deduced from the theories. NAT for example talks about complex systems such as those in a nuclear power plant. Perrow acknowledges that new safety systems are sometimes installed to ostensibly achieve better reliability. But that this can make the system more accident prone because of the new systems higher complexity (Perrow, 1984). This shows that working within a NAT should be done within an existing system. The actors need to come up with ways to reduce the complexity and tightness of coupling in the system. That is the simple conclusion of NAT. HRT concerns itself with the culture, awareness and hierarchy of an organization. Therefore the measures applied from a HRT perspective to become a HRO should not be that costly. And although they don't cost much relatively to physical investments, they do pay off at the same rate. But the problem is that it takes time to build up a HRO. Therefore working towards becoming a HRO should start as soon as possible. The first step of doing this is to reform how one sees and evaluates risk. No risk is too small to consider. No solution is too farfetched to evaluate (Weick et al, 1987). Becoming better at identifying risk within this regional context means that there is a need to have better RVAs.

6.5.1 Using HRT to improve RVAs and implementation of measures

When working with risk analysis one has to consider the risks probability as well as its consequences. Risk can be describes as:

$$R_i = \{\langle s_i, p_i, x_i \rangle\} \qquad i = 1,2,\ldots,N$$

Where s_i is a certain scenario, p_i is the probability of occurrence and x_i is the severity of consequences. One can choose in the equation to put more emphasis on either the probability or the consequences (Kaplan & Garrick, 1981). Svenska Kraftnät has in their RVA template for utility companies included examples of both. See tables 2 and 3 to see the differences.

There weren't any of these matrixes in the public sectors' RVAs. In a practical approach the matrix that emphasises the consequences might seem more sensible. But by understanding the whole picture it becomes obvious that one would have to emphasise the probabilities. Fewer incidents mean more reliability and less risk errors multiplying.

Probability/consequence	Insignificant	Minor	Serious	Severe
Very low				
Low				
Medium				
High				

Table 2. A matrix where consequences are more acceptable as long as probability is low.

Probability/consequences	Insignificant	Minor	Serious	Severe
Very low				
Low				
Medium				
High				

Table 3. A matrix where higher probabilities are more acceptable as long as consequences are low.

Implementation:

When working in a systematic manner one needs to list previous, current and planned measures. Otherwise threats, risks and vulnerabilities could end up being identified and categorized but with nothing being done to reduce the probability of their occurrence. The only RVA which did so was the Region's. And even if they are listed, they need to be implemented.

Implementation is the most important aspect of HRT. The problem with public sector organizations is that they don't have enough incentives to do that (Interview with Henrik Tehler at LUCRAM, 13/4/16). In a paper written by (Larsson, 2016) she concluded that although the municipalities can come up with a lot of measures that needs to be implemented, they rarely do implement them. In 2011 61% of the measures disappeared the following year. And 20% remained with the same status. In 2012 there was some improvement with 34% of the measures disappearing and 16% remaining with the same status.

One could try to implement the measures by following a strict hierarchy from the government to the county board to the Region and municipalities. But the rigidity in that is also a source of danger to flexibility. So there is a fine balance to tread. In Sweden there is also a rooted tradition of municipal self-rule. The reason some municipalities don't want to take part of county programs is because they feel that they know best what is in their own interest. But at the same time without incorporating the safety routines, measures and procedures in the daily work they are never institutionalized and it doesn't become the culture of the organization.

When safety becomes a *culture* rather than *rules*, it can draw from both the clarity of hierarchy and the flexibility of decentralization. When it is the safety culture rather than rules and procedures that drives the work there is no need for surveillance. When the system is flexible there can be room for human judgement. Take for example a human controller that has to deal with emergencies that have no precedents. With a stricter hierarchy he would need to defer back to a higher level even if the problem is manageable at a lower level wasting precious time. To boost this kind of culture, work is needed to improve worker morale too. Unsatisfied workers are inattentive and uncreative workers. The county for example doesn't have to make the municipalities attend their training programs. The municipalities could form their own ones, suited for them, as long as they encourage a safety culture.

Decoupling the system:

An automated system can suddenly shut down without controllers being fast or smart enough to deal with it. A human controller wouldn't take on more traffic in the first place more than his mind can handle. The systems complexity would remain at the human level (Weick et al, 1987). The reason Weick presumes that human judgement would be better is because they work hard and improvise to make their work environment as risk free as possible. To be able to do that they need what he calls discretion, latitude, looseness, enactment and slack (Weick et al, 1987). This could also be seen as strengthening worker morale because they would have the freedom to do their jobs in a manner they say fit.

Intelligence gathering:

Another thing that HRT stresses is thorough risk detection (Weick et al, 1987). This can be incorporated in the RVA by having better intelligence gathering. Today there is intelligence gathering being conducted in both sectors. But the purpose of those is more of an immediate kind. They are there to detect looming, impending or imminent dangers. Intelligence gathering should also be used to detect long term strategic risks and risks originating in other sectors. Lessons can be drawn from dangers found in other parts of the country or the world. One comprehensive study was the one done after the Sandy storm. But that study's main purpose was to learn lessons in crisis management. Similar studies could be conducted with the purpose of learning of new threats, the probability of their occurrences and preventative measures taken against them.

6.5.2 The ways NAT can be used to evaluate developments in the grid

Smart grid is a generic term for the solutions used in modernizing the electric grid. This includes such things as using new technologies, software, control systems, business models and components.

Smart meters enable a two way communication between the meter and the utility company and across shorter timespans. This will enable better information gathering about the state of demand. Today demand is estimated based on historical statistics. Deviations from that are then regulated. The deviations can't be too large and the system is therefore suited for stable demand figures each year. Smart grids will help to automatically detect actual demand directly and voltage fluctuations and then signal for plants to increase production or reroute power to prevent an outage. When there is peak demand prices could go up to encourage less use reducing the risk of overloading the system thereby encouraging demand response. The production and distribution, even at local levels, can become more automated. The difference between this and a human operator is that the automatic system is faster. This reduces the number of incidents but if the system was to malfunction it would be harder to recover from (Perrow, 1984) (SOU, 2013).

There are risks associated with a more automated system. It will become more "tightly coupled" meaning errors will spread faster throughout it. This will happen in two ways.

Because it is automated the system will work faster and affect more parts of it. Secondly because the system works faster it will become harder to detect errors. The increased complexity will make it more vulnerable for antagonistic cyber-attacks and more prone to accidents (SOU, 2013). But more complexity in the system is inevitable as smaller actors are getting involved in the market and as more power comes from renewable energy sources and local producers. It is harder to make these energy sources produce electricity on demand and therefore more flexibility is needed in the system. Smart grids could then be said to encourage the decentralization of the grid. NAT encourages decentralization but warns against complexity. Here they go hand in hand. So in this instance NAT cannot be entirely transplanted to the electric market. And because the development of smart grids is an evolution rather than a revolution and because the complexity increase is not all too dramatic, the risks are therefore acceptable. There is even a way to further decrease the complexity of smart grids. The automation could be used to process information and not for decision making. The decision making could still be left at the hands of human operators whom could use the information as support in their decision making (Perrow, 1984).

Dynamic Line Rating will help determine load capacity in real time instead of basing it on seasonal estimations, thereby making more use of transmission lines. More loads could be put on the system within the bounds of its capacity (SOU, 2013). The HRT warns against this as this is literally a kind of creeping towards the edges, not when it comes to safety procedures, but when it comes to technical capacity. From a NAT perspective this would increase the coupling of the system, reduce safety buffers, rely more on technology and thereby making it more accident prone.

The NAT and HRT are still relevant when discussing the electric grid. They show that the concept of smart grids, though praised by many institutions including Swedish Smart Grids, the US energy department, the Institute of Electrical and Electronics Engineers, the International Electro-technical commission and ABB company, should be adopted with caution and with attention paid to the new challenges that it brings with it.

Another interesting development in the grid design is the so called self-healing system. This operates so that robotic agents distributed in the grid communicate to each other the state of the grid in order to decide on the best response. There are today agents in the grid but they are isolated and pre-programmed with only a few simple decision rules. The agents being developed are context dependent, evolving and cooperating. Agents would be specialized and adaptive. Some would act as sensors, some as frequency stabilizers, some as protection agents, some as hidden failure monitoring agents, some as event identification agents and some as restoration agents. This kind of system would automatically be able to detect anomalies but also determine the correct course of action to rectify the anomaly. This would massively increase the intelligence and automation in the system and thereby its complexity. This will be mitigated by having a redundant software infrastructure, that is, two parallel agent systems. If one were to malfunction, it could be rebooted while the other takes over its functions (Amin, 2001) (Perrow, 1984). It is difficult to say if this would create more problems than it solves. On the one hand the system does become more vulnerable to cyber-attacks and any simultaneous failure would create larger effects. But on the other hand, there is a need for a function of self-healing to increase the power reliability in the future. A possible compromise is to have human control elements at the top of the chain. Even though the system would still be too complex for them to handle it could mitigate some of the effects.

7. Conclusion

In this section I will summarize the answers to the questions posed in the research question part and evaluate the answers.

- What are the current approaches actors take to prevent power outages and how do they work?
- Why do actors choose these approaches and what choosing-patterns form?
- How do these approaches and patterns affect the power supply?
- How can better approaches be evaluated and achieved?

7.1 Conclusions on Scanian approaches to reliability

The approach to power reliability is one of practicality. Reasonable measures are set in place to prevent and reduce certain known risks. The details of the measures can differ from actor to actor. But the common denominator is that they serve the current need of the system. The future needs are often discussed. But the future risks associated with new measures and approaches can be hidden. Sometimes they are considered in evaluations and sometimes they are not. This stems from the practical approach adopted by the actors. The approaches they have are there to solve current needs in power reliability.

The measures fit within a spectrum ranging from simple lectures, to advanced drills to building entire new power lines to strengthen redundancy. They correspond to roughly the NAT or the HRT. Some of the measures fall within a grey-zone but they are usually not the most prominent approaches. So both the public and private sector do use the NAT and HRT but in an indirect manner. This means that they follow the implications of the theories without being positively aware of them. This is also confirmed by LUCRAM. The approaches then are either NAT or HRT but implemented in an unaware and unsystematic manner. They are used in a more practical manner which confirms the original hypothesis. This approach is usually cost effective but doesn’t produce perfect reliability.

7.2 The patterns in using different approaches

There is a pattern which shows the measures that are chosen by what actors. It provides for some interesting conclusions.

The public sector uses HRT more for several reasons. First the public sector doesn’t own that much technical infrastructure to invest in in the first place. Secondly, they can’t do much to incentivize the companies to invest either as they lack the financial and legal tools. Thirdly their responsibility is mainly to coordinate the actions of different actors. A smooth organization capable of crisis management is what is needed and HRT is what helps them get there. The companies on the other hand deal mostly with technical infrastructure even if they do have to organize the company internally. They are punished by the government if they don’t provide reliable power supple. At the same time they need to deliver power to make a profit. HRO is a long term and continuous investment whose effects are not always easily measured. But micro-grids, redundancy and maintenance are fixed measures which can be tracked and quantified.

The public organization’s different geographical, sectorial and financial circumstances contribute to different measures within the HRT spectrum. For the utility companies the negative and positive incentives engrosses the motivation to be practical which leads to similar measures.

The differentiation in approaches is good as it creates a requisite variety in the approaches used. They can complement each other and help mitigate each other's deficiencies. This is not without problem though. The actors don't always act in a unified matter because of fragmentation. This leads to missed synergy effects.

7.3 Implications of the approaches and theories:

The usage of a practical approach has left the region utterly unprepared against the largest threat; disruption of imported power. This flaw could prove critical if left unaddressed. But the region is relatively prepared for the most likely threat; natural events. This points to show that the practical approach is "practical" but not totally reliable.

The theories used could be of assistance in building a more systematic approach to power reliability. The HRT has clear conclusions on the characteristics of an HRO and on the organizational culture. This can be transplanted to actors within the power business. The NAT can provide for ways to evaluate future measures designed to improve reliability. But the theory has to be modified. Sometimes the grid must become more complex to become less centralized. This will lead to the grid eventually becoming less complex. So it is an indirect way of reducing complexity.

8. Further research

In the future the concepts of NAT and HRT could be further elaborated. There can be a more thorough classification of the approaches. The categorization could then be made more nuanced. To come to more exact results and conclusions of this study more actors can be involved in future studies. Interviews could be conducted with two different people in within each actor. This would open up interesting aspects of perhaps discovering different approaches within one organization. With more time, the patterns analysed can be analysed in more detail. To better test this paper's conclusions, other regions can be studied using the same theoretic framework and research question. Comparisons could then be made as regards to the two regions' approaches, patterns in approaches and the reason for their similarity or difference.

One could also broaden the study by applying the methods, research subjects, theoretic framework and so on, on the next phase of power resilience which is management and consequence reduction. HRT would be especially applicable here as organization is essential to this. Instead of RVAs one could study the actors' SWOT analyses and their approaches to improve shortcomings and reduce the consequences of an outage. There is much more work needed in this field. The future of power research looks bright indeed.

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