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**Development of a Situation Awareness System for
Disturbance Management of Electricity Networks**



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Development of a Situation Awareness System for Disturbance Management of Electricity Networks

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Abstract

Numerous major disturbances in electricity networks have affected Finland in recent years, due to weather conditions like storms or snow loads on trees. In addition to Distribution System Operators (DSOs), major disturbances affect on other stakeholders such as Mobile Network Operators (MNOs), fire and rescue services and municipalities. Thus, the information exchange between stakeholders during disturbances plays an essential role in disturbance management.

In the field of electricity distribution, studies usually focus on finding ways to prevent disturbances or to recover the network quickly. However, achieving high-level reliability can easily become expensive. This thesis introduces a method to improve the restoration process of electricity networks and resilience of the society during major electricity network disturbances through Situation Awareness (SA) system. It combines information about electricity network outages, disruption of mobile networks and sites that are highly dependent on electricity. Most studies relating situation awareness to disturbances in electricity networks are focused on the transmission networks. This study focuses on distribution networks.

This study investigated problems with present methods for information exchange during major disturbances using semi-structured interviews. Additionally, the main information needs of each stakeholder were gathered via interviews and workshops. Information needs were observed to vary by organization. The present systems used during disturbances do not take this variation in account.

Further, a concept for an SA system, extended to all stakeholders during major disturbances in electricity networks, was developed and demonstrated. Several versions of the demonstration were presented to test the method during this study. The development process went through several iterations, and each version of demonstration was evaluated with usability methods and through user focus groups in workshops and in interviews. The developed demonstration differs from existing systems, because it combines and processes information from multiple DSOs and MNOs.

The demonstrated SA system was shown to be useful for improving the restoration process of electricity networks by combining the information about the interdependencies of stakeholders (e.g., electricity and mobile networks). Further, the each demonstrations of a SA system included a database of critical sites, which stores information about sites or customers that are highly dependent on electricity supply. This method improves the resilience of the society by accounting for the most vulnerable sites in a community during disturbances in electricity networks.

The situation awareness system can change the restoration process of electricity networks so that the sites that are most dependent on electricity can be dealt with more efficiently.

Additionally, authorities can plan their processes more efficiently based on the locations of these sites. An SA system can decrease the workload of users during disturbances by decreasing the number of views.

Overall, this thesis presents a method to combine information from existing systems into an SA system for disturbance management. It highlights the importance of information exchange between different stakeholders during major disturbances in electricity networks. The results of this study can be used for further product development of SA systems.

Preface

This study was carried out at the Laboratory of Electrical Energy Engineering, Tampere University of Technology (TUT) during the years 2010-2018. The work was supported by Finnish Funding Agency for Technology and Innovation (TEKES) and Academy of Finland under the projects "Development of the Risk Analysis and Management Methods in Major Disturbances in the Supply of Electric Power", "Smart Grids and Energy Markets (SGEM)", "Cooperative planning and monitoring of mobile and electricity networks", "Flexible Energy Systems (FLEXe)" and EL-Tran. The additional funding provided by Jenny and Antti Wihuri foundation, Ulla Tuominen foundation, KAUTE foundation and Finnish Foundation for Technology Promotion is greatly appreciated.

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Acronyms

2G	second generation
3G	third generation
AMR	Automatic Meter Reading
BIE	Building, Intervention and Organization
CIS	Customer Information System
DA	Distribution Automation
DMS	Distribution Management System
DSO	Distribution System Operator
FICORA	Finnish Communications Regulatory Authority
FMI	Finnish Meteorological Institute
FTA	Finnish Transport Agency
GIS	Geographical Information System
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol Secure
IT	Information Technology
JDL	Joint Division of Laboratories
MNO	Mobile Network Operator
NASA-TLX	NASA Task Load Index
NIS	Network Information System
PLC	Power Line Communication

RTU	Remote Terminal Unit
SA	Situation Awareness
SART	Situation Awareness Rating Technique
SCADA	Supervisory Control And Data Acquisition
SMS	Short Message Service
SOAP	Simple Object Access Protocol
TSO	Transmission System Operator
UK	United Kingdom
UML	Unified Modeling Language
UMTS	Universal Mobile Telecommunications System
VAPEPA	Voluntary Rescue Service
VIRVE	Government Official Radio Network
WFS	Web Feature Service
WMS	Work Management System
XML	Extensible Markup Language

List of Publications

- I Krohns H., Strandén J., Verho P., Sarsama J., “Developing communication between actors in major electricity distribution network disturbances” *Nordic Electricity Distribution and Asset Management Conference 2010*. 6.-7.9.2010. Aalborg, Denmark.
- II Krohns H., Hälvä V., Strandén J., Verho P., Sarsama J., 2011. ”Demonstration of Communication Application for Major Disturbances in the Supply of Electric Power” *CIGRE International Symposium – The Electric Power System of the Future*. 13.-15.9.2011. Bologna, Italy.
- III Krohns-Välimäki H., Strandén J., Pylkkänen K., Hälvä V., Verho P., Sarsama J., 2013. “Improving shared situation awareness in disturbance management” *CIGRE 22nd International Conference on Electricity Distribution*. 10.-13.6.2013. Stockholm, Sweden.
- IV Krohns-Välimäki H., Aalto H., Pylkkänen K., Strandén J., Verho P., Sarsama J., 2014. ”Developing Situation Awareness in Major Disturbances of Electricity Supply” *IEEE PES Innovative Smart Grid Technologies, Europe 2014 (ISGT EU 2014)*. 12.-15.10.2014. Istanbul, Turkey.
- V Krohns-Välimäki H., Haapanen J., Aalto H., Strandén J., Verho P., 2015. “Demonstration of the Inter-Organizational Situation Awareness System to Major Disturbances” *CIGRE 23rd International Conference on Electricity Distribution*. 15.-18.6.2015. Lyon, France.
- VI Krohns-Välimäki H., Haapanen J., Verho P., Säe J., Lempiäinen J., 2015. "Combined Electricity and Mobile Network Situation Awareness System for Disturbance Management" *IEEE PES Innovative Smart Grid Technologies, Asia 2015 (ISGT ASIA 2015)*, 4.-6.11.2015. Bangkok, Thailand.
- VII Krohns-Välimäki H., Säe J., Haapanen J., Verho P., Lempiäinen J., 2016. "Improving Disturbance Management with Combined Electricity and Mobile Network Situation Awareness System" *International Review of Electrical Engineering (I.R.E.E.)*, volume 11, number 5, pages 542-553, October 2016
- VIII Krohns-Välimäki H., Aalto H., Haapanen J., Verho P., 2018. "Improving resilience of society in major disturbances of electricity supply" *Disaster Prevention and Management* Submitted.

1 Introduction

Several problems exist in the information exchange between organizations during disturbances in electricity networks. Usually during disturbances, municipalities and authorities receive information via the web pages of DSOs, like transformer level maps or lists that show the outages and their duration and through phone conversations. The problems in information exchange affect the recovery process of critical infrastructures, like electricity and mobile networks. One of the biggest problems has been poor SA of stakeholders, including DSOs, fire and rescue services and municipalities. In one case in Finland, the municipality could not reach their local DSO because they only had a public customer service telephone number which was congested. In another case, a local DSO thought that a retirement home was a regular customer. Thus, it was not prioritized in the restoration process. (Finnish Energy 2015, Landstedt 2007).

In Finland, storms like Pyry and Janika in 2001, four storms in the summer of 2010, Tapani and Hannu in 2011, Seija and Eino in autumn 2013, Valio in 2015, a snow storm at Juupajoki in 2015 and Rauli in 2016 caused widespread and long-lasting disturbances in the electric power supply. In the worst of those disturbances, some individual customers were without electricity for several weeks. Similar problems have occurred in Sweden (e.g., storms Gudrun in 2005 and Per in 2006). Additionally, snow loads on trees caused widespread disturbances in Finland in January 2011 and January 2015. In addition to storms that affected rural areas, Hurricane Sandy caused widespread disturbances in the eastern USA in October 2012, including major cities (e.g., floods caused outages to Manhattan in New York City). In July 2014 and January 2015 in Finland, disturbances in the electricity network caused disruption to mobile networks. Some areas were left without mobile network coverage for almost a day. (Strandén et al. 2009, Strandén et al. 2014, Con Edison 2012, UCTE 2007, U.S. Department of Energy 2004).

Storms and other severe weather conditions induce many of the long-lasting and widespread disturbances, called "major" disturbances. Nonetheless, there have also been major disturbances that have not been especially long-lasting but extremely widespread, like the disturbances in the transmission systems in the USA and Canada in 2003, in Helsinki, Finland in 2003, and in central Europe in 2006, which were caused by human error. Some of these caused negative societal consequences. (Con Edison 2012, Finnish Forest Center 2016, Strandén et al. 2009, Strandén et al. 2014, Talouselämä 2016, UCTE 2007, U.S. Department of Energy 2004).

Typically, the disturbances caused problems in telecommunication, water supply, residential heating and the conditions of farm animals. Loss of heat in homes even led to some evacuations. The problems with telecommunications also affected safety phones (and emergency buttons). Thus, they caused difficulties for home-care patients. Additionally, disturbances can affect on special health care patients who depend on medical equipment

at their residence. (Con Edison 2012, Landstedt 2007, Strandén et al. 2009, Strandén et al. 2014, UCTE 2007, U.S. Department of Energy 2004).

Since storms in Finland in 2001, DSOs have been obligated to pay graduated compensations, called "standard compensations" to customers when an outage is last 12 hours or longer. The standard compensations as currently implemented, direct the restoration process of electricity networks to minimize the number and duration of the disturbances. Additionally, regulations require DSOs to minimize customer outage costs. Thus, DSOs typically organize their restoration process starting with the customers with the highest consumption. (Finnish Energy Market Authority 2007, Finnish Energy Market Authority 2011a, Strandén et al. 2014).

After the storms in Finland in December 2011, the Finnish Electricity Market Act was changed to improve the reliability of the electricity network. The new addition to the legislation requires DSOs to prepare a contingency plan for disturbances. Further, the Finnish Electricity Market Act was changed so that the maximum duration of an outage will be six hours in urban areas and 36 hours in rural areas. Starting in 2029, this will apply to all customers. Moreover, the standard compensations were increased by adding more gradations and increasing the maximum value from 700 to 2,000 euros by 2018. DSOs must prepare development plans to describe how these limits will be achieved and how the electricity supply for the sites that are important to the resilience of the society are secured. Further, the new legislation requires that the DSOs should participate in the formation of a situation awareness and supply any information relevant to this purpose to the responsible authorities. (The Finnish Electricity Market Act 2013).

1.1 Motivation and the scope of the thesis

During major disturbances in electricity, multiple stakeholders are involved, such as DSOs, MNOs, contractors, fire and rescue services, emergency response centers, police, municipal governments, volunteer organizations and individual customers. All stakeholders are obligated to maintain their capability to carry out their duties related to major disturbance. Additionally, major disturbances create more duties, (e.g., fire and rescue services bring people out of elevators, and municipalities arrange evacuations and check on the welfare of elderly people). (Landstedt 2007).

In relevant studies (Ley et al. 2012, Panteli et al. 2015, Schweer et al. 2013, Strandén et al. 2009, Strandén et al. 2014), the following problems with situation awareness of stakeholders during major disturbances has been noticed:

- Information is distributed to several information sources.
- Awareness about available information is missing.
- There are issues with information policy.
- There are uncertainties in the information.
- There are issues with terminology.
- There are problems perceiving interdependencies between information.

The policy and workload issues prefer that common awareness by every stakeholder is not needed. Instead, information should be individualized or localized. Similar issues

have been noticed also in Finland. (Horsmanheimo et al. 2017, Ley et al. 2012, Panteli et al. 2015, Schweer et al. 2013, Strandén et al. 2009, Strandén et al. 2014).

This study focuses on the problems with situation awareness during major disturbances in the electricity network. The research questions are following:

- How to improve the restoration process of electricity networks?
- What methods would improve the information exchange between stakeholders during disturbances?
- How can the resilience of the society during disturbances be improved?

1.2 Objectives of the thesis

The main objective of this research is to study a new method to improve restoration processes of electricity networks and the resilience of the society during major disturbances in electricity networks. The interdependencies and information exchange between different stakeholders during major disturbances are analyzed to determine the basis for the new method. Further, a concept for an SA system for the major disturbances is developed. The concept is tested by developing a demonstration in which a combined SA system for electricity and mobile networks is demonstrated.

1.3 Thesis contribution

The main contributions of the thesis can be summarized as follows:

- The main information needs of the stakeholders during major disturbances in electricity networks are analyzed.
- A concept and a demonstration of an SA system, extended for all stakeholders of the major disturbances in electricity networks, is developed to improve disturbance management. It is different to existing methods because it combines and processes the information of multiple electricity networks and mobile networks.
- After analysis, it is determined that the developed SA system can be used to improve the restoration process of electricity networks by combining the information about the interdependencies of the stakeholders, (e.g., electricity and mobile networks).
- A criticality database of the developed SA system, which stores information about sites or customers that are highly dependent on electricity supply, is presented. This method improves the resilience of the society by taking into account the most vulnerable sites of the society during disturbances in electricity networks.

1.4 Research process and methods

Several methods were used in this research process. The main method used was the Action Design Research method (Sein et al. 2011) which was used to develop a demonstration of the situation awareness system. The method deals with two challenges: 1. a problem situation that arises in a specific organizational setting is encountered and evaluated ; and 2. an Information Technology (IT) artifact that addresses the problems typical of

the encountered situation is developed. The design process considers the users' influence and its ongoing use in context.

The method consists of four stages: 1. Problem Formulation, 2. Building, Intervention and Evaluation, 3. Reflection and Learning and 4. Formalization of Learning. The design process is conducted by the design team, which includes researcher(s) and practitioners. Versions of the system are presented to end-users in the middle of the design process. (Sein et al. 2011).

Other methods were used to supplement different phases of the design process. Each method is presented briefly in the following subsections. Publications related to each method are presented in Figure 1.1.

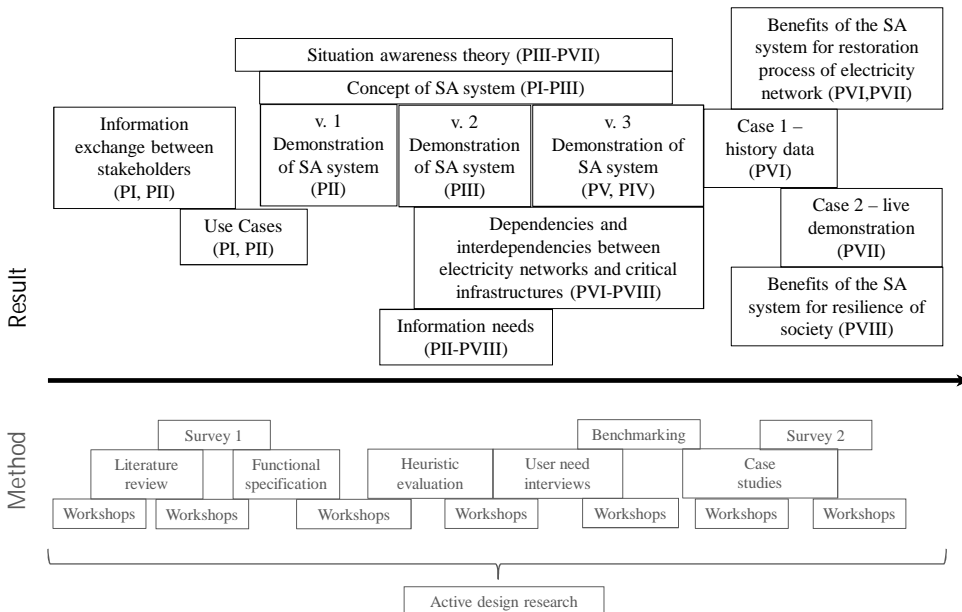


Figure 1.1: Content of the dissertation. Above each topic is the research method used. "P" with number is a reference to the publication related to the dissertation.

1.4.1 Literature review

The literature review was conducted in different parts during the study process. At the beginning of the study, the major disturbances in electricity networks were studied. This was done by studying literature, reports of the disturbances made by authorities or DSOs, scientific publications and published news. The focus was on information exchange between different stakeholders.

Additionally, the different situation awareness systems used during disturbances were studied. In addition to scientific publications, the web pages of the systems were used. The study of the existing situation awareness systems were conducted throughout the research process.

Further, the theory of situation awareness and developing situation awareness systems was studied to understand the information exchange process. In this part, scientific publications and literature were studied.

At the end of the study, the literature review focused on information systems that DSOs use to form their awareness of the disturbance situation, and to create benchmarks to match the developed system to existing systems. This analysis was based on scientific publications and system vendors' brochures.

1.4.2 Survey

In the beginning of the research process, a survey was distributed among the Finnish DSOs in 2009 in cooperation with VTT Technical Research Centre of Finland. The survey was addressed to 86 DSOs, which comprised the majority of DSOs in Finland. Two DSOs were excluded from the survey because they operate in industrial environments with a limited number of customers. In total, 51 replies were received including one representing two DSOs within the same energy corporation. Thus, the response rate was 52 out of 86, (i.e. about 60%).

The main aim of the survey was to determine the DSOs' view of major disturbances in electricity networks. The questions concerned the following topics:

- The measures taken by the DSOs to prevent long-lasting or widespread interruptions in the electricity supply.
- DSOs' possible experiences related to major disturbances in the supply of electric power.
- Estimation of the frequency of major disturbances in the supply of electric power.
- Assessment of the measures taken in emergency situations by the different parties to prevent major disturbances in the supply of electric power, including different types of customers (electricity users), and the different stakeholders of the society, in which it operates, on the basis of the law.
- Opinions on the need to develop the exchange of information in respect to major disturbances in the supply of electric power.

Another survey was done in 2016 of Finnish citizens in cooperation with Tampere University. The main topic of the survey was citizens' opinions on energy-related issues. The survey was addressed to 4,000 citizens and 1,349 replies were received. Thus, the response rate was 33.7%. This survey asked for, opinions related to the security of the electricity supply.

1.4.3 Workshops

During the research process multiple cooperative workshops were conducted to gather information from the different stakeholders during disturbances in electricity networks. Participants in the workshops represented DSOs, fire and rescue services, municipalities and information system vendors. Additionally, some workshops on other projects were visited to gain information about the latest research related to disturbance management.

The structure of the workshops was informal. Workshops consisted of discussions and presentations of the latest research results. Some of the workshops covered topics related to the participants' operating area. For example, one of the workshops was held in a municipality, and the discussion centered on disturbances that have occurred in their operating area, and what their main responsibilities are in those situations.

One part of the workshops was to represent the most recent results of this research. This usually involved a demonstration of the newly-developed situation awareness system to participants, after which their opinion of it was asked.

1.4.4 Functional specification

The functionalities of demonstration of situation awareness system were specified using the Unified Modeling Language (UML) method (Chonoloes et al. 2011). Class diagrams were used to represent structural information, and use case diagrams were used to describe the users' interaction with the system. The definitions were based on the results of the first survey and workshops from this study.

1.4.5 Demonstration

As a main part of the action design research method, a demonstration of an SA system was implemented. Based on the results of the specification, a concept for the SA system was developed. Then, the first version of the demonstration was created based on the concept. Overall, three different versions of the demonstration were developed during the study.

Demonstrations used existing information systems of stakeholders, primarily DSOs'. Demonstrations consisted of web site that combined information about disturbances in electricity networks from DSOs' information systems with information from other stakeholders, such as mobile network operators, weather services and information about customers or sites that are highly dependent on electricity supply.

The main purpose of the demonstration was to test how situation awareness can be shared during disturbances in the electricity supply. Each version of the demonstration was presented to stakeholders in workshops carried out in this study to gain their opinions.

1.4.6 Heuristic evaluation

Part of this study involved usability studies. They were conducted using two methods: heuristic evaluation and semi-structured user-need interviews.

The heuristic evaluation was conducted for developed demonstration, based on Nielsen's heuristic evaluation method (Nielsen 1993). The purpose of the evaluation was to make the demonstration more user-friendly. The heuristic evaluation was done by observing the user interface and gaining information about benefits and drawbacks of the user interface.

The problem of the heuristic evaluation is that each individual evaluator may miss some of the usability problems in a user interface. It is recommended that there are three to five evaluators to recognize most of the problems (Nielsen et al. 1990). In this study, three different evaluators observed all of the heuristic elements from the demonstration. The evaluators were three students from the Tampere University of Technology, who had not been part of the developing process of the system before the heuristic evaluation.

1.4.7 User-need interviews

Semi-structured user-need interviews were done in two sections. First, the present methods to achieve situation awareness were studied. In addition, it was determined which information interviewees required to carry out their duties. The interviewed were representatives of one municipality and two fire and rescue services in Finland. The interview was semi-structured (Bernard 2006) (i.e., questions were planned in advance, but some were changed during the interview based on the previous answers).

In the second part of the interviews, a version of the developed demonstration was presented for the second fire and rescue service and municipality and interviewees' opinion of it was asked. The demonstration was further developed based on the results of these interviews.

The interviewee from the first fire and rescue service was working as an operator in their main fire and rescue service. This fire and rescue service served 22 municipalities, with seven DSOs covering their operating area. The respondent from the second fire and rescue service was working as a chief fire officer. This fire and rescue service served 11 municipalities, with two DSOs covering their operating area. The interviewee from the municipality was a leader of social services, who was also responsible for contingency planning of the social services. The second fire and rescue service that was interviewed operates in the same area as this municipality. In addition, the last two interviewees participated in the cooperative workshops.

1.4.8 Case Studies

In this study, a demonstration of a situation awareness system was developed through an iterative process. The concept for the demonstration was based on the literature review, survey and workshops. The demonstration was improved throughout the research process.

The demonstration presented to two different instrumental case studies (Grandy 2012). In the first case study, a disturbance in electricity and mobile networks which occurred in Finland in 2014 was studied. The case was simulated in the demonstration and compared to the real-life case. The results of the comparison were analyzed to study the capability presented by the demonstration to improve the restoration process of electricity and mobile networks. One DSO provided transformer status information about the area and one mobile network operator provided configuration and status information about the mobile network base stations. In addition, an online remote field service provider provided information about the communication link statuses of the switches in the electricity network.

The second case study was done as a continuous real-time study. A live version of the demonstration was developed to study how the situation awareness system could be conducted. The main aims were to study how information can be exchanged between stakeholders effectively during disturbance situations, and how the real-time situation awareness system can be conducted by using the existing systems.

The demonstration combined information from four DSOs and one MNO. The demonstration presents mobile network service interruptions and electricity network outages at the transformer level on a map view. The studied area was the operation area of the chosen DSOs. In addition to mobile network coverage, the base stations that had faults were shown on the map.

1.5 Publications

This dissertation consists of the following publications:

1. Publication I: "Developing communication between actors during major electricity distribution network disturbances"
 - a) Content: Publication describes the stakeholders during major disturbances, their main responsibilities and the information system applications they use.
 - b) Publication presents results of survey conducted among DSOs in Finland.
 - c) Main contribution of the publication is identifying the information exchange needs between stakeholders during major disturbances in electricity networks.
 - d) Author's role was to participate in creating the survey and analyzing the results, along with co-authors M.Sc. Janne Strandén, Prof. Pekka Verho and M.Sc. Janne Sarsama. Additionally, the author identified the main problems in present methods of information exchange. The author did all the analysis and the writing of the publication. Other authors contributed to publication mainly by giving feedback on the written manuscript.
 - e) Limitations and possible errors: The paper was written a long time ago. Some parts of the literature review and some survey answers may be different at present. A term "common operational picture" was used in this study instead of "situation awareness" which would be more appropriate to the study.
2. Publication II: "Demonstration of Communication Application for Major Disturbances in the Supply of Electric Power"
 - a) Content: Publication presents use cases of information exchange during major disturbances created during cooperating workshops in the study. In addition, a concept for a situation awareness system and demonstration based on the concept is described.
 - b) The main contribution of the publication is a concept for situation awareness system to improve information exchange during major disturbances.
 - c) Author's role in this publication was to create use cases based on the results of the workshops and to analyze the results of the survey concerning the use cases. The author was the main creator of the situation awareness system concept. The author did all the analysis and the writing of the publication. The demonstration presented in this publication was implemented by M. Sc. Vesa Hälvä. The author supervised the demonstration, ensuring it was implemented based on the concept. Authors J. Strandén, P. Verho and J. Sarsama contributed to the publication mainly by giving feedback on the written manuscript.
 - d) Limitations and possible errors: The survey was done only for DSOs. Therefore, the use cases cover only their view on the subject. The results of this study could be improved by including the other stakeholders in the survey.
3. Publication III: "Improving shared situation awareness during disturbance management"

- a) Content: Publication studies the role of shared situation awareness during major disturbances and presents a demonstration of a situation awareness system.
 - b) The main contribution of the publication is to present a method to improve information exchange during disturbances through a situation awareness system.
 - c) Author's role was to study the literature on situation awareness and create a concept for a situation awareness system. Additionally, the author did all the analysis and the writing of the publication. Further, the author participated in the development of the demonstration with M. Sc. Kaisa Pylkkänen and V. Hälvä. The author supervised the demonstration to ensure it was implemented based on the concept. Authors J. Strandén, P. Verho and J. Sarsama contributed to the publication mainly by giving feedback on the written manuscript.
 - d) Limitations and possible errors: The demonstration was not tested in this part of the study. With different testing methods, the results of this paper would be more reliable.
4. Publication IV: "Developing Situation Awareness during major disturbances in electricity Supply"
- a) Content: Publication presents a theory of inter-organizational situation awareness. In addition, the paper identifies benchmarks of existing situation awareness systems used during major disturbances in electricity networks.
 - b) The main contribution of the publication is to provide information on the present methods used in information exchange during major disturbances. In addition, it represents how the developed concept for the situation awareness system differs from present methods.
 - c) Author's role was to analyze how the theory of shared situation awareness is suitable in cases of major disturbances. In addition, the author studied existing systems and compared them to the developed concept of a situation awareness system. The demonstration presented in the publication was implemented by K. Pylkkänen and V. Hälvä. The author supervised the demonstration to ensure it was implemented based on the concept. Additionally, the author did all the analysis and the writing of the publication. Authors M. Sc. Hanna Aalto, J. Strandén, P. Verho and J. Sarsama contributed to the publication mainly by giving feedback on the written manuscript.
 - d) Limitations and possible errors: More systems could have been chosen to benchmark for a better view of the current situation.
5. Publication V: "Demonstration of the Inter-Organizational Situation Awareness System to Major Disturbances"
- a) Content: Publication describes how the situation awareness system extends the integration of Distribution Management System (DMS) in an unusual direction by considering the other stakeholders during disturbances. In addition, the publication presents a new version of the situation awareness system demonstration, developed based on the results of the user need interviews.
 - b) The main contribution of the publication is that it presents a method to combine information from multiple DSOs and other stakeholders into one view.

In addition, it presents a new method to improve the restoration process of electricity networks by using a database of customers or sites, that are highly dependent on electricity.

- c) Author's role was to participate in designing and executing the user-needs interviews with H. Aalto. The author analyzed the results of user-needs interviews, and based on the results, further developed the concept for the situation awareness system. Additionally, the author did all the analysis and the writing of the publication. The demonstration presented in this publication was implemented by M. Sc. Jussi Haapanen and the user interface was designed by the author, along with H. Aalto and J. Haapanen. The author's primary contribution was to ensure that the demonstration was implemented based on the concept. Authors J. Strandén and P. Verho contributed to the publication mainly by giving feedback on the written manuscript.
 - d) Limitations and possible errors: The demonstration was tested by presenting it to interviewed stakeholders. The number of those interviewed was small. With a wider test group and more testing methods, more information about the system's suitability during disturbances could have been gained.
6. Publication VI: "Combined Electricity and Mobile Network Situation Awareness System for Disturbance Management"
- a) Content: Publication describes present sources of situation awareness during disturbances. In addition, a case study simulated with developed situation awareness system demonstration is presented.
 - b) The main contribution is a new method to study interdependencies between electricity and mobile networks using a combined situation awareness system. The system can be used to improve the disturbance management of both networks.
 - c) The publication was written in cooperation with M. Sc. Joonas Säe, J. Haapanen, P. Verho and Prof. Jukka Lempiäinen. Author's role was to analyze the present sources of situation awareness during disturbances and to analyze the results of the case study. Additionally, the author was responsible for writing most of the electrical engineering and situation awareness parts. The demonstration presented in this publication was implemented by J. Haapanen. The author's primary contribution was to ensure that the demonstration was implemented based on the concept. J. Säe was responsible for writing parts covering the wireless communication and simulating the wireless communication parts for the demonstration. The publication was finalized in cooperation with J. Säe. P. Verho and J. Lempiäinen contributed to the publication mainly providing support during the research phase and by giving feedback on the written manuscript.
 - d) Limitations and possible errors: In this paper, some issues arose due to the studied mobile network coverage data. The modeled coverage data for the edges of the disturbance area may not be correct because overlap of the coverage from different base stations was not considered. A better understanding of the demonstration would have resulted if a larger area had been modeled.
7. Publication VII: "Improving Disturbance Management with Combined Electricity and Mobile Network Situation Awareness System"

- a) Content: Publication presents a new method to improve disturbance management of electricity and mobile networks through a combined situation awareness system. The implementation of a live demonstration is presented.
 - b) The main contribution is a method to improve the restoration process of electricity and mobile networks using combined situation awareness system.
 - c) The publication was written in cooperation with J. Sæe, J. Haapanen, P. Verho and J. Lempiäinen. The author was responsible for the study phases from the electricity networks' point of view by analyzing the interdependencies, analyzing the existing systems and designing the live demonstration. In addition, the author analyzed the benefits of the system from DSOs' and authorities' point of view. The demonstration presented in this publication was implemented by J. Haapanen. The author's main contribution was to ensure that the demonstration was implemented based on the concept. The author and J. Haapanen wrote the electrical engineering parts, and the author is responsible for the situation awareness parts. J. Sæe was responsible for writing the parts covering the wireless communication and simulating the wireless communication parts for the demonstration. The publication was finalized in cooperation with J. Sæe. and J. Haapanen. P. Verho and J. Lempiäinen contributed to the publication mainly by providing support during the research phase and by giving feedback on the written manuscript.
 - d) Limitations and possible errors: The paper is focused mainly on DSOs' and mobile network operators' point of view. If the information from other stakeholders had been combined into the live system, there would be more information about the benefits of the system. Another limitation with this study was that while the live demonstration was observed, no major disturbances occurred. During a wider disturbance, the testing situation would have been more accurate.
8. Publication VIII: "Improving resilience of society during major disturbances in electricity supply"
- a) Content: Publication presents a new method to improve the resilience of the society through a situation awareness system.
 - b) The main contribution is a method to change the restoration process of electricity and mobile networks, so that the resilience of the society is considered.
 - c) The publication was written in cooperation with H. Aalto, J. Haapanen and P. Verho. The interviews were planned and conducted in cooperation with H. Aalto. Additionally, the author did all the analysis and the writing of the publication. The demonstration presented in this publication was implemented by J. Haapanen. The author's main contribution was to ensure that the demonstration was implemented based on the concept. The publication was finalized in cooperation with H. Aalto and J. Haapanen. P. Verho contributed to the publication mainly providing support during the research phase and by giving feedback on the written manuscript.
 - d) Limitations and possible errors: A limitation of this study was that while the live demonstration was observed, no major disturbances occurred. During a wider disturbance, the testing situation would have been more accurate.

1.6 Structure of the thesis

This thesis is divided into six chapters. The contents of each chapter are summarized below.

Chapter 2 is an introduction to the major disturbances in electricity networks. It presents the background of the thesis. Chapter 3 introduces the present methods of forming situation awareness during disturbances in electricity networks. Additionally, it presents the main information needs of the stakeholders during disturbances. The design process and implementation of an SA system is introduced in Chapter 4. Further, the results of the case studies are presented in that chapter. The main analysis of the thesis can be found in Chapter 5. The conclusions of the thesis can be found in Chapter 6.

2 Major disturbances in electricity networks

This chapter describes the major disturbances in electricity networks. The nature of the major disturbances and the roles of stakeholders during major disturbances are introduced. The focus of this chapter is on the disturbances that have occurred in Finland, because the organization structure of the stakeholders differs in different countries. Additionally, the most data was available from Finland for this study. This chapter is based on the results of the publications [I, II, VII].

2.1 Causes and consequences of major disturbances

In Finland, the electricity supply system comprised of generation, transmission network, sub-transmission networks, distribution networks, low-voltage networks and consumers. The main structure is simplified in Figure 2.1. The distribution network consists of radial lines. In Finland, most of the disturbances have occurred in distribution or low-voltage networks.

In Finland, most of the major disturbances in electricity networks are caused by weather (e.g., storms, snow loads or lightning), especially outside the cities (as seen in Figure 2.2). Additionally, severe weather conditions like hurricanes have caused major disturbances globally. When the disturbance is caused by storms, the weather also usually cause problems with the restoration and repair process (e.g., there can be trees or lot of snow on the streets). (Finnish Energy 2017).

In addition to disturbances caused by storms in Finland, there have been several widespread disturbances caused by human errors in different countries. In the Northeast USA in 2003, the disturbance spread further, due to a lack of information sharing between Transmission System Operators (TSOs), and because of failures in the information system, which delayed the response to the failure of electricity networks. The same year in Italy, a disturbance spread to the entire country due to problems in information exchange between the Italian and Swiss TSOs. A widespread disturbance affected a large part of Europe in 2006, when the operators did not perform a contingency analysis using updated data. Most often, the weather causes problems at the distribution network level and incidents cause problems at the transmission network level. (Strandén et al. 2014, UCTE 2003, UCTE 2007, U.S. Department of Energy 2004).

In Finland, there have been many long-lasting disturbances over the last decade. The major disturbances raised the average interruption duration of customers (as seen in Figure 2.3). If a major disturbance occurred in that year, it may comprise most of the total approximate interruption time for that year (the method of grouping customers

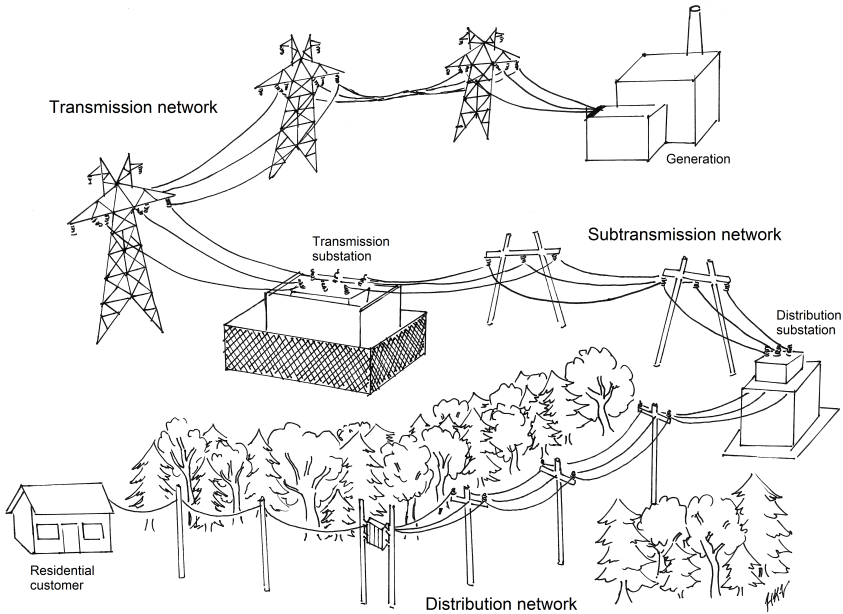


Figure 2.1: Typical structure of electricity network in Finland.

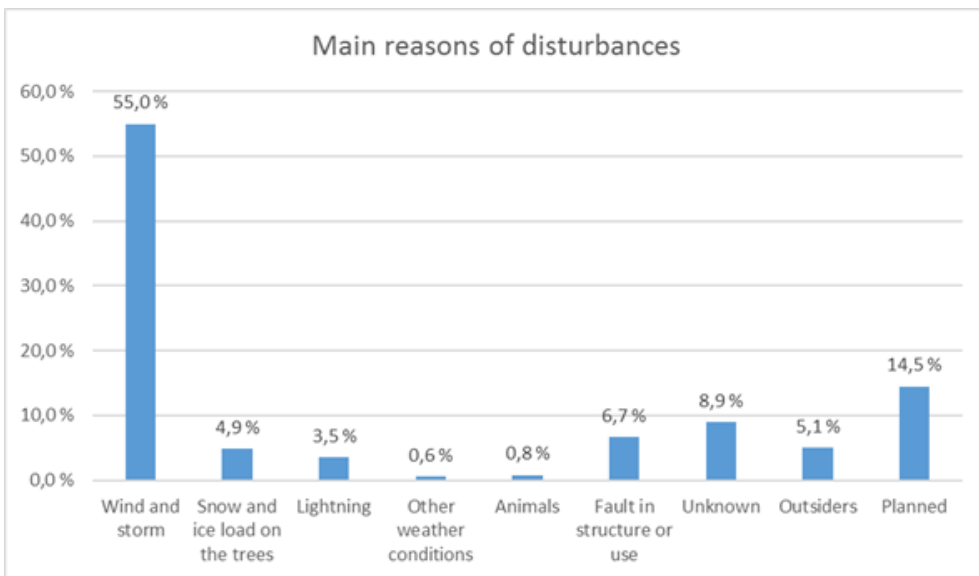


Figure 2.2: Main reasons for interruptions in Finland (Finnish Energy 2017).

based on living area changed in 2005 and 2015, thus there are difference in statistics). However, based on the survey conducted by this study in 2016, 91% of customers are

satisfied with the security of the electricity supply.

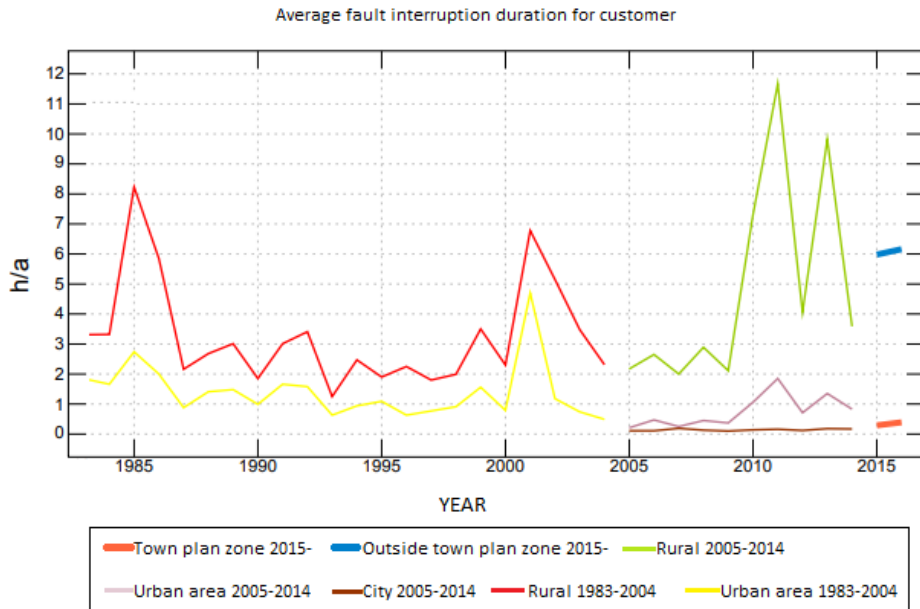


Figure 2.3: Average interruption duration of customers in Finland in years 1983-2016 (Finnish Energy 2017).

Usually, a "major disturbance" in electricity networks is defined in a very system-oriented way. An IEEE Standard major event (i.e. "major disturbance") is defined as follows (IEEE 2012):

- "Major Event: Designates an event that exceeds reasonable design and or operational limits of the electric power system. A Major Event includes at least one Major Event Day."
- "Major Event Day (MED): A day in which the daily System Average Interruption Duration Index (SAIDI) exceeds a Major Event Day threshold value. For the purposes of calculating daily system SAIDI, any interruption that spans multiple calendar days is accrued to the day on which the interruption began. Statistically, days having a daily system SAIDI greater than TMED are days on which the energy delivery system experienced stresses beyond that normally expected (such as during severe weather). Activities that occur on Major Event Days should be separately analyzed and reported."

Another technical definition comes from Finnish researchers: "A major disturbance is a condition in which more than 20% of the customers are without electricity, or the 110kV line, the 110/20 kV primary substation or the primary transformer is out of operation for several hours because of a fault"(Tahvanainen et al. 2007).

For this study, the effects the major disturbance has on society play an important role. Thus, these have been highlighted in the definition. A major disturbance in the supply of

electric power was defined as *"a long-lasting or widespread interruption in the supply of electric power, during which the fire and rescue services and one or more other public actors (municipal government, police, etc.) need, in addition to the DSO, to start implementing measures to reduce possible severe consequences to people and property."*

The characteristics of the most relevant major disturbances in Finland are shown in Table 2.1. In the 2011 storms, the expenses for the entire country of Finland were the most substantial ever. The societal problems caused by each of these major disturbances have been similar. There have been problems with water supply and sewers, interruptions in telecommunication networks, and problems on farms with animals. There have been huge problems with information exchange between the stakeholders. For example, during one storm, the local DSO did not have information that a site was a retirement home; rather, they thought that it was a regular household customer. In another case, the fire and rescue service could not reach the local DSO, because they only had the public customer-service phone number, which was congested. (Finnish Energy 2015, Finnish Forest Center 2015, Finnish Forest Center 2016, Strandén et al. 2014, STT 2013, Talouselämä 2016).

Table 2.1: Major Disturbances in Finland (Finnish Energy 2015, Finnish Forest Center 2015, Finnish Forest Center 2016, Strandén et al. 2014, STT 2013, Talouselämä 2016).

Major disturbance	Number of interrupted customers	Longest interruption experienced by a customer (days)	Total costs of DSOs (M€)	Compensation paid by insurance companies (M€)	Forest damages (Mm ³)
2001 (Pyyri & Janika)	860 000	> 5	> 10	-	>7
2010 (Asta, Veera, Lahja & Sylvi)	480 000	> 42	32	81,5	8.1
2011 (Tapani & Hannu)	570 000	> 14	71	102,5	3.5
2013 (Eino)	> 200 000	> 1	-	30	1.5
2015 (Valio)	230 000	3	17	4	0.5-1.5
2016 (Rauli)	200 000	2	15	3-5	0.15

One problem during disturbances is that the restoration process of the DSO is focused highly on economic aspects and not on the the resilience of the society. At present, the legislation and standard compensation practices are directing DSO's goal to minimize the number and duration of the disturbances in Finland. This is causing expensive measures to improve the resilience of electricity network, (e.g., by laying more cable). However, if there is a method to improve resilience of the society during disturbances, it may decrease the development need of DSOs. This can make the restoration order of the electricity networks more efficient. Thus, it can help the fire and rescue services and municipalities to maintain their duties during disturbances.

In this study, terms "criticality" and "critical" are mentioned in several purposes when discussing major disturbances. The terms were used in following way:

- *"Critical customer: A regular household, which is highly dependent on electricity, e.g. home care patient who has medical equipment that needs electricity to function or elderly citizen, who uses safety phone."*

- *"Critical site: A site, which is highly dependent on electricity, e.g. site of other critical infrastructure such as city water supply."*
- *"Critical time: A time, which critical customer or critical site can be without electricity before there are severe consequences for health or life of people or there are severe economic consequences."*
- *"Criticality of a site: Level of the consequences, if the critical time of the customer or site has exceeded."*
- *"Criticality database: A database, which gathers information about critical customers, critical sites and critical times."*

This thesis does not specify the exact numerical limits of the critical time, and does not define level of the criticality of a site, because there can be substantial differences between those values in different countries and even with different DSOs based on the amount of the customers.

2.2 Stakeholders during major disturbances

Usually, during disturbances in critical infrastructure, such as electricity networks, many stakeholders are involved. The objectives in the situation are dependent on the stakeholders. Thus, it is important to identify the stakeholders and their objectives and motivations during disturbance situations (Kjolle et al. 2012). At workshops organized by this study, it was noticed that the main stakeholders during disturbances in electricity networks are DSOs, subcontractors, fire and rescue services, municipalities and mobile network operators. In addition, police, other authorities and other infrastructure entities can be involved in the situation. The stakeholders covered in this study are limited, based on the ones that were determined, through workshops organized by this study, to be the most common actors during disturbances in electricity. Kjolle et al. (2012) found similar stakeholders on their study.

The main goal of DSOs during disturbances is to restore their network operations as soon as possible. The recovery process is usually planned so that electricity will first be restored to customers with the highest consumption. Individual households and vacation residences are served last. DSOs are obligated to pay so-called "standard compensation" to customers during disturbances. These are graduated payments that are paid to customers when an interruption lasts 12 hours or longer. In 2013, the Finnish Electricity Market Act was changed to improve the reliability of electricity networks. The maximum number of the standard compensation was doubled to 200% of the annual service fee, or 2,000 euros instead of the former 1,000 euros. The new addition to the legislation requires DSOs to prepare a contingency plan for disturbances. Further, it was added to the legislation that the maximum duration of outages will be six hours in urban areas and 36 hours in rural areas, applicable to all customers starting in 2029. DSOs must prepare development plans to describe how these limits will be achieved and how the electricity supply for the sites that are important to the resilience of the society are ensured. Further, the new legislation requires that the DSOs participate in the formation of a situation awareness and supply any information relevant to this purpose to the responsible authorities. (The Finnish Electricity Market Act 2013, Strandén et al. 2014).

Mobile network operators are involved during disturbances in electricity supply, because there is interdependence between these two networks. Mobile network base stations

need electricity to maintain their transmission. They are obligated to keep the base stations functioning for at least three hours during electricity supply disruptions through backup power batteries or other reserve power. (FICORA 2012a, Horsmanheimo et al. 2013, Hyvärinen et al. 2009).

The fire and rescue services are responsible for protecting people, property and the environment in danger (The Finnish Emergency Powers Act 2011). During electricity supply disturbances, fire and rescue services need to maintain their operations, because the law obligates them to maintain their process undisturbed in all cases. Disturbance situations can increase their tasks, (e.g., helping people out of elevators or clearing trees from the street). Fire and rescue services can have numerous DSOs and municipalities in their area of operation. Most of the departments have divided their operation area into smaller areas, each with its own fire chief. Tasks are delegated to rescue departments by the local emergency call center.

Municipalities have multiple duties during disturbances. Like authorities municipalities are obligated to maintain their services undisturbed in all cases (The Finnish Emergency Powers Act 2011). They are responsible for the health of their citizens and for critical infrastructures, such as city water supplies. Additionally, they are responsible for other services, like primary schools and nursery schools. During long-lasting disturbances, municipalities may have to plan an evacuation. In addition, they are responsible for home-care patients who use safety phones, which may not operate during disturbances.

The main goals of each stakeholder during disturbances vary. The municipalities and fire and rescue services have some common goals; both work to protect citizens, which can be difficult during disturbances in electricity or mobile networks. On the other hand, DSOs and mobile network operators are more focused on the business aspect. They want to restore their operations as soon as possible to minimize costs and compensation that they are required to pay to customers.

2.3 Dependencies and interdependencies of critical infrastructures during disturbances

A dependency can be defined as a unidirectional relationship between two infrastructures, in which the state of one infrastructure influences the state of the other. Furthermore, an interdependency can be defined as a bidirectional relationship between at least two infrastructures, in which the state of each infrastructure influences the state of the other (Landstedt 2007). Both dependences and interdependencies between stakeholders occur during major disturbances in electricity networks. Interdependencies between electricity networks and other critical infrastructures affect the restoration process of the electricity network and the resilience of the society during disturbances. Interdependencies can be divided into spatial and functional interdependencies. Spatial interdependence means the proximity of two infrastructures (e.g., telecommunication and electricity distribution cables implanted in same track). Functional interdependence describes the situation when one infrastructure requires the other infrastructure to operate, (e.g., water pumps require electricity to operate) (Rinaldi et al. 2001, Zimmerman 2001). The results of the workshops and interviews were related mostly to functional interdependencies, thus the study focuses primarily on those.

There are different definitions of critical infrastructure. The U.S. President's Commission on Critical Infrastructure Protection (1997) defined an infrastructure as *"a network of*

independent, mostly privately-owned, man-made systems and processes that function collaboratively and synergistically to produce and distribute a continuous flow of essential goods and services," and a critical infrastructure as *"an infrastructure so vital that its incapacity or destruction would have a debilitating impact on our defense and national security."* Furthermore, the Critical Infrastructure Assurance Office (1998) defined critical infrastructure as *"those physical and cyber-based systems essential to the minimum operations of the economy and government."* Both focused on eight critical infrastructures: telecommunications, transportation, electric power, gas and oil production and storage, banking and finance, government services, water supply, and emergency services. (U.S. President's Commission on Critical Infrastructure Protection 1997, U.S. Presidential Decision Directive 1998).

In Finland, the Ministry of Defence has defined the most vital services to society. Based on these vital services, the largest threats to society are defined as a major disturbance in one of the following infrastructures; energy (including electricity networks), telecommunications (cyber threats), transportation and logistics, community development, food supply, financial and banking, public-sector finance, public health and well-being. (Finnish Ministry of Defence 2010, Finnish Ministry of Defence 2017)

At present, the most-used definition of critical infrastructure includes 11 sectors. Based on (Lewis 2006) these sectors are the following: water, agriculture and food, emergency services, public health, telecommunications, energy, chemicals and hazardous materials, postal and shipping, banking and finance, transportation and defense industrial base.

This study focuses on the critical infrastructures that have the most interdependencies between electricity networks and those whose dependency on the electricity have the largest effect on the resilience of the society during electricity supply disturbances. Telecommunications, especially mobile networks, have multiple interdependencies between electricity networks, and affect the restoration process of electricity networks, so they have their own subsection in this thesis.

2.3.1 Interdependences between electricity and mobile networks

Development of electricity networks towards a "smart grid" has increased their dependency on mobile networks (the main processes of distribution networks are described in Figure 2.4). In previous studies, it has been noticed that there are significant interdependencies between electricity and mobile networks. During the storm Tapani in 2011 in Finland, the mobile network coverage decreased 25% due to outages, and it took four days to recover it almost fully. (Clark et al. 2010, Horsmanheimo et al. 2013, Kjolle et al. 2012, Kok et al. 2005, Salomäki 2013, Shahidepour et al. 2003, Rigole et al. 2006, Rinaldi et al. 2001).

The functionality of mobile networks depends highly on the availability of electricity networks. When there is an electricity disturbance, the mobile network is not able to provide any coverage without backup power. However, for example, in Finland, mobile networks still must continue to function, because FICORA has issued a regulation (FICORA 2012a) stating that mobile network base station sites should have backup power for three hours in the case of disturbances in the electricity network. This is usually implemented using backup batteries, since, for example, the availability of renewable energy devices, such as solar panels and wind turbines, are rare at base station sites in Finland, mostly because of their low efficiency rate. Thus, base stations rely on battery

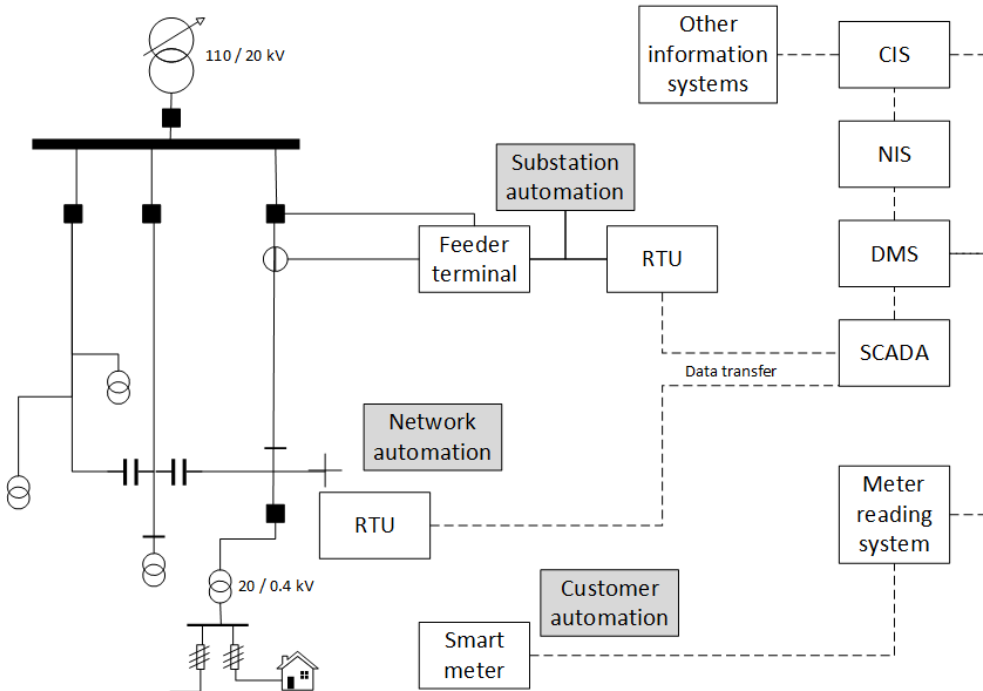


Figure 2.4: Processes of distribution networks in Finland. (Lakervi et al. 2012).

backup power during power disturbances. Still, sometimes the electricity disturbance can last longer than the reserve backup power (e.g., because of storms).

The backhaul connections in mobile networks (i.e., the connections from the mobile operators' core network to the base station sites) are implemented mostly using fiber optic connections. In addition, these connections rely on electricity networks to function. The reliability of the devices in the backhaul transmission lines usually have a greater backup power reserve than base stations, enough to last at least 6–12 hours (FICORA 2012a). The most critical sites even have aggregates to enable longer periods of operation, with logistic contracts to deliver more fuel to these sites when needed.

On the other hand a widespread disruption in the mobile network can affect the electricity network if public mobile networks are congested. While the electricity network can operate without telecommunications, it is necessary for the operation of the Distribution Automation (DA). Traditionally, most of the communication was done using proprietary communication methods and protocols. Nowadays, mobile networks are used in multiple ways in distribution networks, such as DA and communication with repair groups. (Clark et al. 2010, Roy et al. 2011).

Figure 2.5 illustrates an example of a field communication systems used by a DSO in Finland. The main communication between substations and the control center operates through a doubled third generation (3G) network connection. However, in many cases, mobile network operators use the same mast for their base stations, so if the mast lacks power, none of them will function. Thus, a satellite link is used for additional backup.

The number of DA devices in the distribution network has increased in recent years. DA devices improve outage recovery times. Previously, a telecommunication link was

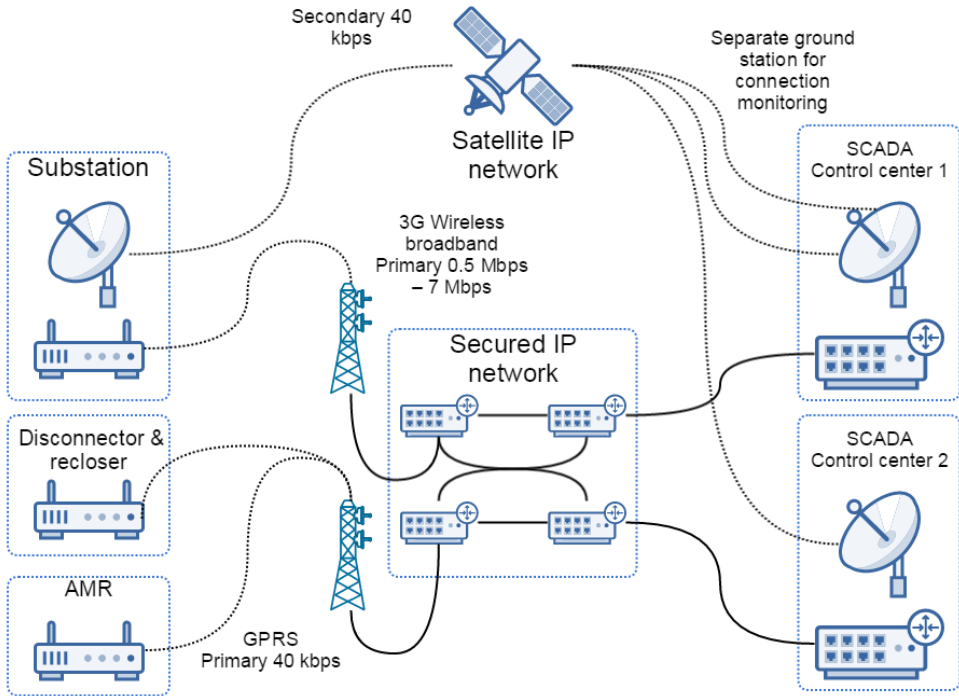


Figure 2.5: A field communication system used by a DSO in Finland.(Haapanen et al. 2016).

only established to the most important parts of the network such as substations. After a remote connection to substations, the use of remote-controlled disconnectors started. The connection between control center and DA devices is often based on mobile network technologies and is not usually backed up. (Chen et al. 2001, Roy et al. 2011).

In recent years, the restoration process of electricity networks has been improved by increasing the number of remote-controlled switches. With them, the restoration time can be improved by several hours. However, some of these switches use the Global System for Mobile Communications (GSM) to communicate. If there is no communication between the remote-controlled switches and substations, a repair team must be sent to enable a manual shutdown of switches, which will slow down the restoration process. (Bernardon et al. 2010, Edström et al. 2010).

Nowadays, in addition to these devices, a connection is also needed for Automatic Meter Reading (AMR). The number of AMR meters has increased in electricity networks. The smart metering devices are used for collecting consumption data, reading and recording signals related to power quality and failure detection. Usually, they use mobile networks for communication. The data is typically transmitted either via Short Message Service (SMS) or the circuit-switched non-transparent GSM data service. Power Line Communication (PLC) is also used together with a mobile network (e.g. for AMR meters). These connections also depend on the mobile network, as part of the communication link to the control center is implemented using a mobile network. (Chen et al. 2001, Liposcak et al. 2013, Roy et al. 2011).

In addition, there are communication links between substations and Supervisory Control

And Data Acquisition (SCADA). Often the mobile network is used for their communication because the price is fair for data transfer with adequate speed. Secondary substations can monitor and control the electricity network remotely. This measurement data is used to monitor the customer power quality. These functions are important for the power system restoration process, because they help to locate faults. Communication requirements for these control signals differ based on the importance of the signals, for example, controlling sectionalized switches with real-time constraints while economic optimization can be omitted without risk to the network. (Hyvärinen et al. 2009, Rigole et al. 2006, Rinaldi et al. 2001).

The remote-controlled devices are not the only part of the electricity networks restoration process that is dependent on mobile networks. The DSOs' work management is highly dependent on mobile networks during disturbances. Repair teams move around while restoring the network. They need communication access to communicate with the control center to locate faults and to obtain the permission to fix them. In addition, they need information about their next task. Most of the communication with each DSO's operator is handled via mobile phones or tablet computers using the DMS service which relies also on the mobile network. If coverage is missing, the repair team can be unaware of how to proceed. In addition, some DSOs use a work management system that locates their team using the Global Positioning System (GPS) to help with task allocation. (Salleh et al. 2009).

The interdependency of electricity and mobile networks creates challenges to reliable operation and control of electricity networks. In addition, it affects modeling, analysis, forecasting and optimization of the both networks. To mitigate the effect of disturbances, these interdependencies should be considered. (Shahidehpour et al. 2003).

2.3.2 Dependences and interdependencies of critical infrastructures on electricity supply

Based on the cooperative workshops and interviews carried out by this study, the interdependencies between different public authorities and electricity network were analyzed. Some of the results were based on experiences of real situations and some based on the cooperation exercises of stakeholders (e.g., Valve 2014) (National emergency supply agency 2014). In this study, the focus is on Finnish critical infrastructures, because the workshops were conducted in Finland. However, interdependencies are similar in other countries. The dependences and interdependencies are described in Figure 2.6, in which a green dotted line means dependency and a blue solid line means interdependencies.

Municipalities are responsible for different critical infrastructures and services, such as water supply and retirement homes. Disturbances in electricity networks can greatly affect on these services. The water supply is one of the most important critical infrastructures. In Finland, municipalities own water supply companies and are therefore responsible for water supply. The water supply is most dependent on the electricity supply, because water pumping is handled by electric pumps. In an electrical disturbance, water towers can be used as long as they have water. However, that process is based on pressure, so the water can be delivered only to areas close to the tower and cannot be delivered to upper floors of high buildings. In some cases, the most critical water pumping stations have been secured using backup power, or with the option to connect removable backup power.

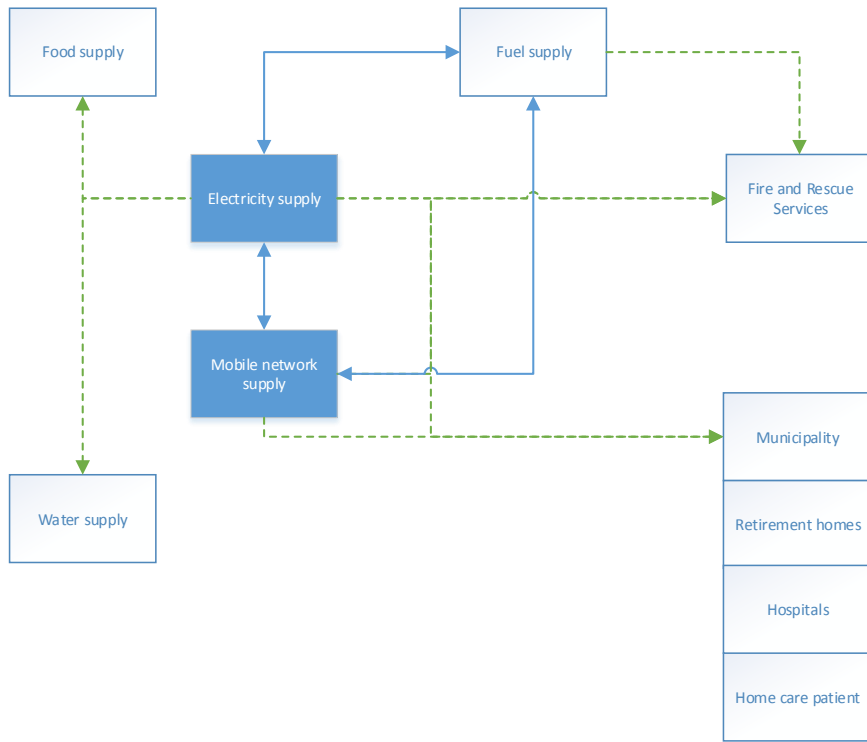


Figure 2.6: The dependencies and the interdependencies of the critical infrastructures.

Public health services are one of the critical infrastructures (Lewis 2006). In an electrical disturbance, public health services can be divided into different parts based on who is responsible for each and whether the service is centralized, like hospitals, or distributed like home-care patients. Usually, the hospitals are prepared for disturbances in electricity networks; for example, many times hospitals have two connections to the electricity distribution network. In addition, the most critical functions of hospitals, like surgical theaters, are secured by their own backup power. Nevertheless, there have been cases where a problem in the hospital backup power system has occurred during a disturbance and caused danger to patients. (Kaleva 2009).

Some home-care patients are highly dependent on electricity, such as patients who use medical ventilator or home dialysis machine. Most of these machines are secured with backup batteries. However, the batteries are only expected to be used for a few hours. During longer disturbances in electricity networks, these patients require help. In Finland, the special health service is responsible for these patients. In the workshops carried out by this study, it was discovered that some municipalities can evacuate the home-care patients if necessary. However, they do not have enough resources to evacuate all the people who may require assistance during a disturbance.

Some municipalities are securing education and child-care facilities by adding backup power to school and nursery buildings. However, many of those do not have any backup.

The main reason to secure the electricity feed to these buildings is to offer a safe place to children to spend their day when there are electricity outages in wide areas, and when these children's parents may be bound to processes to secure the resilience of the society during disturbances.

Fuel supply is a critical infrastructure, that has interdependencies with the electricity supply. The restoration process of the electricity network is dependent on the fuel supply for repair groups. For example, the distances between fault locations can be far during storms. In that case, the repair groups must travel long distances and the fuel consumption can be high. Additionally, public authorities like fire and rescue services requires fuel supply during disturbance situations. In Finland, there are only a few fuel pumping stations that are secured with backup power. All of them are allocated mainly for use by public authorities. Some fire and rescue services have contracts with local fuel pumping stations to deliver backup power to the pumping station to receive fuel for their own use. Some fuel pumping stations have a mechanical backup system to keep pumping fuel successfully. Most of the major disturbances in Finland have occurred in rural areas, thus major problems in fuel supply have not occurred, and there is no experience in how the fuel supply would function in more urgent cases.

The food supply is highly dependent on electricity. Most of the grocery stores have to close during disturbances in electricity networks, because they cannot handle financial transactions without electricity. Some bigger stores can receive cash. However, most of them do not have backup power for their freezers or refrigerators, so the food will spoil quickly. Some municipalities have contracts with the local grocery stores to receive food from them to deliver it to citizens.

In addition to electricity networks, municipalities and fire and rescue services are dependent on mobile networks. In Finland, government authorities have their own telecommunications network Government Official Radio Network (VIRVE) that is secured for disturbance situations. However, some of the VIRVE masts have only six hours of backup power. Thus, some fire and rescue services use satellite phones to secure communications in addition to VIRVE. In addition, some municipalities and fire and rescue services uses landline telephones during disturbances in electricity networks.

Municipalities have elderly customers who uses safety phones. In a disturbance situation, safety phones may stop operating if they do not have mobile network coverage or if their batteries run out. At present, municipalities can send volunteer rescue teams to check the safety phone customers in the outage area or contact the relatives of the customer to see if they know how the customer is handling the situation.

3 Situation awareness during disturbances in electricity networks

This chapter describes how situation awareness during disturbances in electricity networks is formed (publications [I-VIII]). Further, it represents the sources of situation awareness used by different stakeholders during disturbances, and introduces the problems with present methods for sharing information (publications [VII-VIII]).

3.1 Theory of situation awareness

The concept of situation awareness has been developed in the military and aviation industries. Since, it has been used across different industries, such as air traffic control, automotive, automation, environment, C4i (command, control, communication, computers and intelligence), and power supply (Connors et al. 2007, Panteli et al. 2013, Panteli et al. 2015, Stanton et al. 2001). There are multiple competing theories for SA, such as three-level model (Endsley 1995), the perceptual cycle model (Smith et al. 1995, Sandom 2012) and the activity model (Bedny et al. 1999). The most acceptable model has been Endsley's three-level model (Endsley 1995). In this study, Endsley's theory is used in designing the inter-organizational situation awareness system. This theory is selected because it was well-known, and one of the most highly-cited models of SA.

According to Endsley (Endsley 1995), SA is the triad of "perception," "comprehension" and "projection." In this three-level SA theory, the first level is to perceive the status, attributes and dynamics of relevant elements in the environment. At the second level, comprehension of the current situation will be created based on the information received at the first level. This means understanding the meaning of the information. The third level of SA is the projection of the future of the situation. Formation of the SA is an iterative process. During the situation, new data is received and comprehension can be developed. Thus, the projection is improved. (Endsley 1995, Endsley et al. 2008, Endsley et al. 2011, Endsley 2015). Figure 3.1 illustrates the three-level SA model. Most of the studies about SA in the electricity network are focused on the TSO's or DSO's SA. However, the disturbance situation is more complex, because there are multiple actors which have interdependencies. (Connors et al. 2007, Endsley et al. 2008, Panteli et al. 2013, Panteli et al. 2015).

The basic theory of SA is based on an individual's situation awareness, and is usually extended to the team, or as a "shared situation awareness." The "team situation awareness" means that every member of the team has a unique situation awareness that others do not know. However, all members can have some awareness together. Some of the information is shared for all members, and they have a common awareness of that

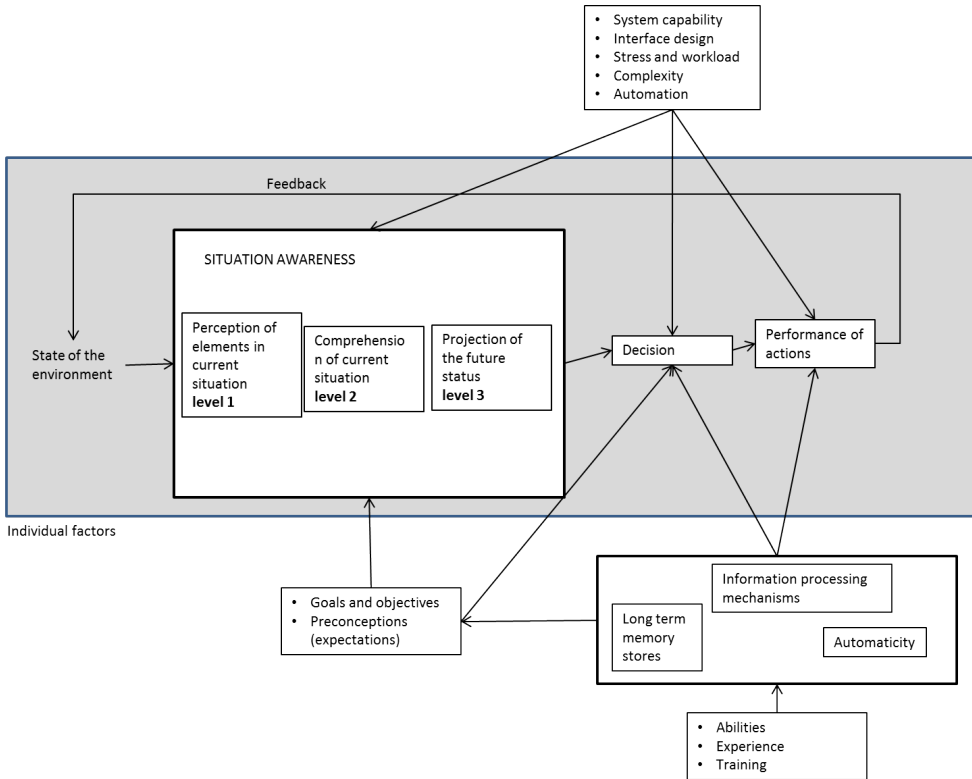


Figure 3.1: Three levels of situation awareness based on Endsley's theory (Endsley 1995).

(illustrated in Figure 3.2). In some cases, there can be also different teams cooperating so that they form a team of teams. (Endsley 1995, Endsley et al. 2008, Endsley et al. 2011, Endsley 2015, Nofi 2000, Panteli et al. 2013, Panteli et al. 2015) In Shu and Furuta's definition of team SA, the knowledge of a dynamic organization structure is highlighted: *"Two or more individuals share the common environment, up-to-the-moment understanding of situation of the environment, and another person's interaction with the cooperative task.* (Shu et al. 2005).

There are some criticisms to Endsley's theory e.g. that the approach is too linear and prevents the transformation from earlier levels before current level is ready (Dekker et al. 2004, Endsley 2015, Sorensen et al. 2011, Timonen 2018). Another criticism concerns that whether the model is process or product oriented. Based on Klein et al. (2007) and Salmon et al. (2008) Endsley's model presents the process and product separately. However, Endsley has answered on these criticism on Endsley (2015). Based on Endsley, the model is not linear by its nature. In the model, good level of SA in the lower levels improves the capability to be successful in latter levels. Additionally, Endsley ensure that the dynamic process is supported by the model.(Endsley 2015)

Furthermore, there are some problems in using the theories of team SA (Endsley 1995) in the case of the disturbances in electricity networks. During disturbances, teams coordinate with other teams, mainly from different organizations. In Salas et al.' (1992) definition of the team, the main features of the team are that they have a common goal, their specific roles are defined and they are independent. The problem in the case of

disturbances is that the organizations hardly have any common goals. DSO's goal is to return electricity as soon as possible to minimize cost. Fire and rescue services' goal is to save people and property from damage. Municipalities' main goal is to keep their citizens safe and retain consistent water and food supply. Further, the claim of specific roles in the definition does not always apply. The actors have specific roles based on their roles in the society. However, there are no established practices which would define the roles during a disturbance situation. According to (Owen et al. 2013) the current models of teamwork do not perform well given the complexity of multi-organizational emergency situations, because the problem is not mainly team performance. Rather the interfaces between teams need to be aligned well to avoid problems.

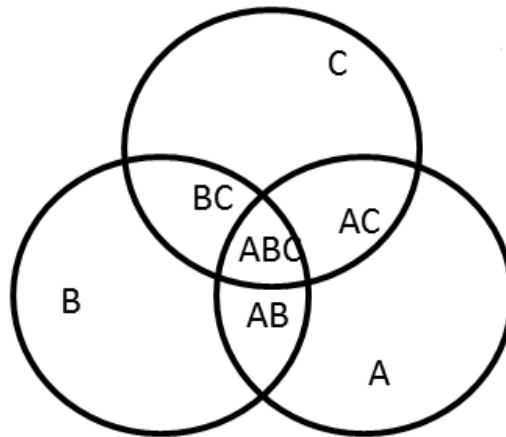


Figure 3.2: Illustration of shared SA (Endsley 1995).

As in many emergency situations, the organizations communicating during disturbances in electricity networks rarely interact with each other in normal situations. During a disturbance, information exchange happens in a high-demanded, highly stressful situation. In this kind of complex situation, coordination breakdowns are common and can cause huge problems. According to Owen et al. (2013), organizational culture influences stakeholders' thoughts and actions in multi-organizational emergencies. Thus, organizational and socio-cultural frameworks play an important role while analyzing the systems and organizational processes that influence multi-organizational teamwork. Additionally, it is important to recognize the communication and coordination challenges between teams or organizations to face the complexity of large-scale future events. (Owen et al. 2013).

As an extension to team SA theory (Endsley et al. 2011), in which, the sub-goals need to be common, in inter-organizational SA, it is most important that the sub-goals of different actors affect each other. In inter-organizational situations, such as during disturbances of the electricity networks, to find the needs of the SA, the interdependences of actors should be determined. In this way, the link between the sub-goals can be found. The best example of this is DSO and mobile network operators: their networks are interdependent. For example, if the DSO restores electricity to the important base station of the mobile network first, it will help their own restoration process by making all remote-controlled switches operational.

The second problem with the definition of the team-specific roles—can be changed easily

by increasing the cooperation between different actors. At present, some DSOs have cooperation between the fire and rescue services. In this case, they already have some common procedures.

In the inter-organizational situations, such as during disturbances in electricity networks, organizations' sub-goals differ from each other. Thus, organizations' interdependencies need to be determined, to determine the situation awareness needs. This way, the link between the sub-goals and information needs can be found. The interdependencies during disturbances in electricity networks were presented in section 2.3.

3.2 Situation awareness of DSO

Most of the studies related to situation awareness of electricity networks focus on the transmission networks. (Connors et al. 2007, Endsley et al. 2008, Greitzer et al. 2008, Panteli et al. 2015). Panteli et al. (2015) have defined the TSOs' SA as a "cognition of elements that enable an effective reaction by operators during routine procedures and electricity disturbances." As with TSOs, to maintain their processes, DSOs require the following information: the present and future state of their responsibility area, the state of adjacent networks that might affect their own responsibility area, the procedures that must be implemented to restore or maintain the system to its normal state, and the maximum number of time available to implement them. However, in case of the DSOs, the role of the other stakeholders is important in a restoration process. Thus, in this study, the focus is extended to cover the information about the situation from the other stakeholders during disturbances.

At present, DSOs form their situation awareness mainly based on SCADA and DMS, which show the outage situation and state information about the electricity network (Kupila et al. 2017, Northcote-Green et al. 2006). Each DSOs' situation awareness is highly focused on their own network. Sometimes, in addition to SCADA and DMS, DSOs are using the Work Management System (WMS) to follow the situation of repair teams and resources, or databases of critical customers to find the most vulnerable sites. Different methods that DSOs use to receive SA during disturbances are presented in the next sections.

3.2.1 Supervisory control and data acquisition

SCADA is one of the main systems that DSOs use to gain the knowledge about events in their own network. It is a chain of equipment that collects and send data from the distribution network to each DSO's operation room. It is used to state estimation of the network and it is responsible mainly for remote measurements and control of the network. The main functions of SCADA are data acquisition, monitoring and event processing, control, data storage archiving and analysis, application-specific decision support and reporting. (Knight 2001, Northcote-Green et al. 2006, Rigole et al. 2006, Shahidehpour et al. 2003).

SCADA collects measurement data about electricity networks via dispersed Remote Terminal Units (RTUs) at substations. The measurement data can be digital data, such as binary system that describes the status of breakers and switches, or analog data that represents power injections and the voltage level at a certain bus. The essential measured data includes information about equipment states (on-line, off-line), voltages, current-flows, frequencies, status change alarms, protective gear operations and operating

variables that might be outside of limits. (Knight 2001, Northcote-Green et al. 2006, Rigole et al. 2006, Shahidehpour et al. 2003).

With SCADA, a DSO can control single devices attached to the network and form an SA of the state of the network connections. Additionally, DSOs can use SCADA to gather and share information on power quality of the whole network or on parts of the network. (Northcote-Green et al. 2006).

3.2.2 Distribution management system

DMS is a group of applications from energy management to real-time management of the distribution network. The base of the DMS is a connectivity database of medium-voltage and low-voltage networks. Usually, the modern DMS is integrated with SCADA, Geographical Information System (GIS), Network Information System (NIS) and Customer Information System (CIS). Further, it provides a geographically-formed view of the medium-voltage network via a graphical user interface. The DMS extends the traditional SCADA by including a connectivity model and control of feeder devices outside substations when SCADA mainly collects and supplies the data. DSOs use DMS to observe and control the network in real time on the map. (Celli et al. 2014, Northcote-Green et al. 2006).

The DMS functions consist of basic functions, applications and outage management. The basic functions handle the integration with SCADA, and management of control-room operations. The applications provide operators the tools to evaluate in real-time and to perform calculations and analysis. There are some differences in the applications, based on the DSOs. Applications can be field crew management, electrical state estimation, topology supervision or simulations. Further, the outage management consists of several functions, which can include the whole situation from fault detection, or taking a customer call, diagnosing the fault location, managing the field crew, executing the switching operations to restore operations, and finally reporting the incident. (Celli et al. 2014, Grillo et al. 2010, Northcote-Green et al. 2006, Rahimi et al. 2014).

DSOs use the DMS to support decision making for network control. It gives them an SA of the state of their network, its topology and operations in the network. Thus, it is highly important to DSO in forming the SA of their own network during disturbances. Further, the DMS can be used for supplying data for SMS service or public web pages of the DSO. (Kuru et al. 2009)

3.2.3 Information about critical customers

Usually the fixing order during disturbances is based on the locations of customers with high consumption or the faults that cause the most trouble with the electricity supply. In many cases, DSOs are unaware of critical infrastructure or customers whose lives are dependent on electricity in the disturbance area. (Elenia 2017, Kuru et al. 2009, Northcote-Green et al. 2006, Salomäki 2013).

The workshops of this study revealed that some DSOs have information about these customers and sites that are highly dependent on electricity, such as nursing homes. However, this information is rarely updated, it is usually only updated if the customer or site contacts the DSO to change the information, so most of this information is outdated and unreliable.

3.2.4 Information from other stakeholders and service providers

In addition to their own systems, DSOs use multiple different sources from other stakeholders and services related to disturbances in electricity networks. The most used services are weather forecasts and warnings. DSOs prepare for disturbances based on the weather forecasts, from which some estimation about the duration of disturbance can be made.

Moreover, the information about the state of the mobile network during disturbance is significant for DSOs. Usually, DSOs use the web pages of MNOs and Finnish Communications Regulatory Authority's (FICORAs) to receive an image of the problems in mobile networks. Some DSOs have agreements with some MNOs to exchange information between each other. These services are presented more precisely in chapter 3.3.3.

3.2.5 Situation awareness systems used by DSOs

A few situation awareness systems are used during disturbances in electricity networks in Germany. DSO MITNETZ STROM has developed a system called "PRONET SIS" which delivers information about outages to authorities. Rescue coordination centers and municipalities were chosen as main users of the system. The required information about planned and unplanned outages from the network control system are filtered and sent to authorities. The data contains information about the outage, location, and geographical data of the substation, internal information about the affected power stations, the number of interrupted customers and a link to Google maps. The information is sent from the system via email to the rescue coordination centers and can be integrated into their system. The municipalities get more accurate and personalized information from the system. The information is sent to municipalities via SMS that contains a phone number to contact the DSO if needed. (Schweer et al. 2013).

Another system developed in Germany is "Sicherheitsarena" (SiRena) ("security arena" in English) developed through the Infostrom project (Ley et al. 2014). The system is based on a digital map and a resource repository. It allows adding different types of internal and external information, such as place marks and weather information. Additionally, the system has a filtering function to show and hide information resources from the map or to add new information to the map. The system can be used via mobile phones and home computers. The resource repository is used to register, describe and rate the available resources. (Ley et al. 2012, Ley et al. 2014).

In Finland, State Security Networks Ltd offers a situation awareness system, KRIVAT, that combines information from different stakeholders like DSOs and telecommunication operators. The system shows a map based view that combines disturbances in electricity networks and mobile networks into the same view. However, the disturbances in the mobile networks are presented with symbols, so an accurate coverage area is not available. Additionally, the system includes a discussion forum for all stakeholders, including meteorologists. A secured telecommunication connection to the users of KRIVAT is offered in addition to the SA system. (State Security Networks 2017).

Another system developed in Finland is Gridwise. It is an SA system for DSOs to follow disturbance situations, managing installation tasks and work management. The system helps to achieve an overall picture of the DSO's network. Additionally, information about weather forecasts and fire and rescue services' tasks are integrated into the system. The system can be used to send information about outages to customers via e.g. mobile app or

SMS. A real-time view of the system is offered to stakeholders like authorities to receive information about the disturbance. The system can be customized for different users. (Tieto 2017).

Additionally, DSO Elenia in Finland has developed its own SA system for disturbances. It is designed for DSO's operators and contractors. The system includes functions for general operations management, outage management of medium-voltage and low-voltage level networks, outage notifications management and management of field resources. It is based on a map view in which information is presented at the service area level. A resource management function manages the contractor partner resources in the field as a cooperatively with contractor partners. Additionally, the contractor partner can see the current fault situation in their responsibility areas at glance. (Kupila et al. 2017).

Some situation awareness systems designed for emergency situations can be used for the disturbances in electricity networks. In Canada, the Multi-Agency Situational Awareness System (MASAS) was developed for exchanging information between organizations in emergency or disturbance situations, such as during flood season. The system can present information about weather, earthquakes, fires and electricity outages on a map. (CanOps 2017a, CanOps 2017b, Pagotto et al. 2012). Another example of more general SA system is Situational Awareness of Critical Infrastructure and Networks System (SACIN) which was developed in research purposes. The system covers the sectors of critical infrastructure defined by Lewis (2006) including power. (Puuska et al. 2017, Puuska et al. 2018, Timonen et al. 2014)

In Sweden, the TSO Svenska Kraftnät offers an SA system, SUSIE, for DSOs and other stakeholders related to disturbances in electricity networks. The system presents live information about outages from different DSOs on a map. Additionally, it includes information from external systems like weather forecasts. One main element of SUSIE is a resource database in which stakeholders can inform others about available resources. Further, the system can be used to send announcements via the Swedish radio system. (Elsamverkan portalen 2017) These situation awareness systems are compared more precisely in section 5.1 in Table 5.1.

3.3 Situation awareness of the other stakeholders and customers

Authorities and municipalities are using multiple information sources to achieve SA during major disturbances in electricity networks. Fire and rescue services are involved with multiple different stakeholders including municipalities, DSOs and emergency response centers. Additionally, municipalities are responsible for multiple services and infrastructures, such as schools and water utilities. Thus, achieving SA can be complex. Like DSOs, MNOs must follow the status of their own network during disturbance situations. (Horsmanheimo et al. 2017).

In Finland, the DSOs share information about the disturbance to other organizations mainly via phone conversations or using transformer-level maps and outage lists on the DSOs' public web pages. These are mostly functions that are based on DMS. The information includes location and the duration of the outage and other necessary information. Further, some DSOs provide so-called "DMS service" for local fire and rescue services. It has a specific display that uses the same information as DMS. This system is originally designed for subcontractors of DSOs. (Elenia 2017, Kuru et al. 2009).

The primary methods that fire and rescue services, municipalities and MNOs use for creating SA during disturbances in electricity networks are described in following sections. The information is based on the results of the workshops and literature review.

3.3.1 Fire and rescue services

Fire and rescue services use their own systems to keep track of their own tasks and units during disturbances. In addition, they follow weather forecasts and warnings sent to authorities from weather services to predict disturbances. They start preparing for disturbances as soon as a storm is coming. The workshops carried out by this study and the relevant study (Horsmanheimo et al. 2017) revealed that in Finland, the fire and rescue services mainly use the public web pages of the local DSOs and the web page of Finnish Energy (Finnish Energy 2018), which offers information about outages at the municipality level, to gain information about disturbances. As mentioned in section 3.2.4, some DSOs provide DMS service for fire and rescue services.

The information about outages is used only after the fire and rescue service gains rescue missions related to it. Users of the DMS service are operators in the control room of the fire and rescue service and senior fire officers. Usually, the DMS services present the location of the distribution network and parts of the network that are working properly. Faulty feeders are shown in an alternate color, such as white. The service is used mainly for locating outages, the number of the residents in the outage area and to determine which DSO is responsible for it. Sometimes, also the estimated length of the outage is observed from the service.

Further, fire and rescue services share information to municipalities and the media. They mainly use e-mails, phone calls, SMS messages and the government official communication network VIRVE (“Viranomaisverkko” in Finnish) for that. In some cases, a representative from a fire and rescue service follow the disturbance in the DSO’s operating room as a contact person. In workshops, it was revealed that sometimes, a fire and rescue service shares a screenshot from the DMS service of the outage area to the municipality.

3.3.2 Municipalities

Based on information gained during the workshops in this study, municipalities have the most problems with information exchange during disturbances in electricity networks. In most of the municipalities, the management group is following the entire disturbance situation. They combine information from multiple databases, maps and DSOs’ public web pages to achieve SA. In addition, some local fire and rescue services sent them SMS messages if the Finnish Meteorological Institute (FMI) had announced a weather warning to authorities. They use DSOs’ public web pages to gain information about the location and estimated duration of the disturbance. This information is combined with information from their residents. Usually, there is no direct method of information exchange between municipalities and DSOs. It can be handled by the local fire and rescue service, for example.

Different services of municipalities form their own situation awareness related to their tasks. The home-care system uses DSOs’ public web page and addresses from their own databases to find customers who are without electricity. In some cases, if there are problems also with mobile networks, the home-care team can make extra checks on patients or inform patients’ relatives about the situation. In addition, municipalities use the resident database to locate elderly people who are not home-care patients.

Municipalities share information about their situation to local fire and rescue services or the Voluntary Rescue Service (VAPEPA) mainly via phone calls or emails. Municipality management groups share information for their own organizations via internal web pages. Press releases are used to inform residents.

3.3.3 Mobile network operators

Like DSOs, MNOs use mainly their own systems during disturbances in electricity networks. They receive fault information from their base stations directly to the system. These include warnings about service- or transmission-related misbehavior, or information about problems related to equipment functionalities. Thus, if the base station site equipment is not able to access an electricity network and uses backup power, MNOs should know about it. In addition, in Finland some MNOs have agreements with the DSOs to receive information about electricity network outages. Like other stakeholders, MNOs follow weather forecasts to prepare for possible disturbances in their network.

For other stakeholders and customers, different MNOs provide information about disturbances on their public web pages. FICORA has set minimum requirements for what the level of accuracy should be for information, such as how the disturbance is visualized on a map (FICORA 2012b). However, this differs greatly between different MNOs. Some even show coverage outages for a single base-station level. Additionally, FICORA has its own web service which combines the disturbance information of different MNOs. However, the information is shared only after severe or very severe disturbances and only a rough area where the disturbance affects the mobile network coverage is shown.

There are similar services in other countries, such as in the United Kingdom (UK) and in Australia, where a few operators have a service that shows the coverage areas and unexpected issues or planned maintenance on a map. Both systems only show areas that are searchable within it. Moreover, the systems do not show the clear influence area. Instead the problems are presented with symbols on a map. Thus, it is difficult to form an image of the affected coverage areas. In addition, one operator in the UK listed the problem areas on their web page. However, specific information on the locations was not shown. (Tele2 AB 2017, Telefónica UK Limited 2017, Telenor AB 2017, Telia Company AB 2017, Telia Finland Oyj 2017a, Telia Finland Oyj 2017a, Virgin Mobile Australia 2017, Vodafone 2017).

3.3.4 Customers and media

Customers and media had the most restricted SA during disturbances. In Finland, most of the DSOs present the outages of their own network on transformer-level map on their public web page. The information include location and the duration of the outage and other necessary information. Additionally, Finnish Energy is gathering this information on their web page and showing all outages at the municipality level. Furthermore, some DSOs offer a SMS service that sends information about the beginning of the outage, estimated duration time and the estimated time that outage will end, for customer. (Elenia 2017, Finnish Energy 2018, Kuru et al. 2009).

3.4 Problems with situation awareness during major disturbances

A primary result of the workshops and interviews was that there are multiple problems that hinder receiving SA during disturbances in electricity networks in Finland. Information is spread to multiple sources, and some stakeholders do not have any information exchange between each other. The biggest problems have occurred in the lack of interoperability between rescue services, DSOs and MNOs. Similar problems have occurred worldwide, such as in Sweden, Germany and North America (Landstedt 2007, Ley et al. 2012, Ley et al. 2014, Schweer et al. 2013, U.S. Department of Energy 2004).

The main problem with all stakeholders has been that there are too many sources of information, which increases the workload of the users during a highly stressful situation. The complexity of the present methods is presented in Figure 3.3. It has been simplified for illustration by presenting the information exchange between one representative of each stakeholder. However, in a real disturbance, there are multiple similar connections, because the operation areas of the stakeholders differ.

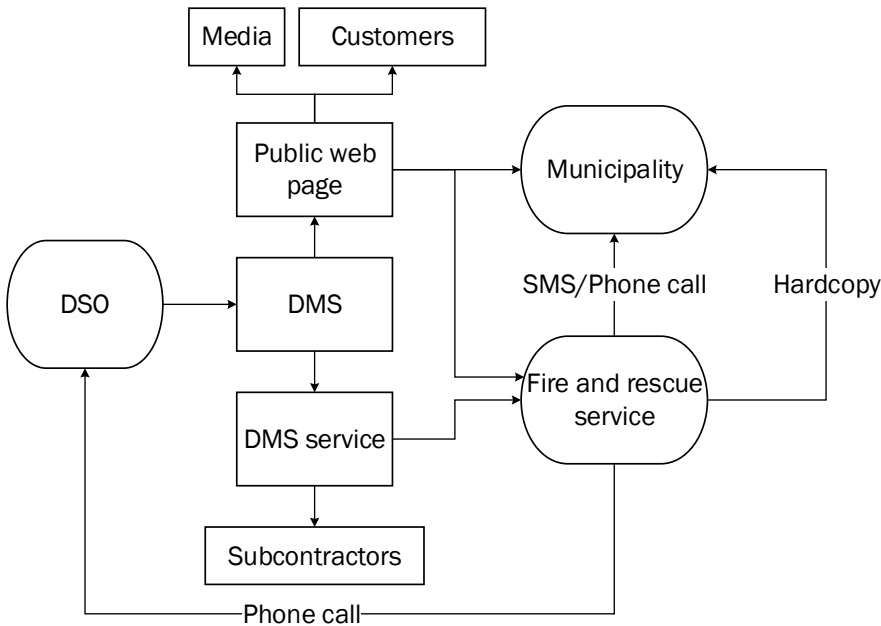


Figure 3.3: Present methods of information exchange during major disturbances.

Another problem is that present methods are focused to present situation awareness on Endsley's (Endsley 1995) level 1 (perception) and level 2 (comprehension) mostly, they do not process the information for projection of the future (level 3). The projection is done by users of the systems like operators of DSOs. The levels of SA that present methods offers are listed in Table 3.1

Table 3.1: Levels of SA, that present methods offer.

SA Level	Information offered by present methods
Level 1	Outages of electricity networks Location of important base stations of mobile networks Location of high consumption of electricity Location of repair teams Current weather data Locations of remote-controlled devices are known Information about location of their own critical sites, (e.g., water pumping stations). There is information about the location of customers whose lives are dependent on electricity
Level 2	Information that there is a disturbance situation in electricity network Information that there is a disturbance situation in mobile network
Level 3	Weather forecasts

Some contradiction occurred in interview responses related to the DMS service. The interviewees considered that the DMS service improves the situation awareness of the fire and rescue services. However, they said it is inadequate for their needs. One problem with some DMS services was that they are use copy of a view in the system that is originally designed for use by DSOs' operators and subcontractors. Thus, they can be complex to use for fire and rescue services. For example, the user interface uses professional terminology that is not common for fire and rescue services. Thus, some users prefer DSOs' web pages or communicating via phone calls to DSOs. Additionally, one problem for fire and rescue services is that they are not able to send any information back to DSOs using present systems, such as information about trees on power lines.

In addition, differences in the operation areas of stakeholders are causing some problems; for example, in the fire and rescue service operation area, there can be multiple DSOs or vice versa. The DMS service presents information only from one DSO, so several systems are required to achieve overall SA in widespread disturbances. Additionally, fire and rescue services have difficulties finding out which DSO is responsible for an outage—in particular, when the information about the outage is received from the web pages of the DSO. The web pages present the outages usually at the transformer station level, so it is difficult to detect which individual citizens or customers do not have electricity.

Based on the workshops and interviews, municipalities have the most problems in information exchange. They must rely on information about disturbances that comes from the web pages of the DSOs or other public sources; in one instance, the municipality had problems contacting the local DSO, because it had only the public customer service number for the DSO. Likewise, DSOs' have little knowledge of critical sites within municipalities. In one case, a DSO did not know that one customer was a retirement home; rather, they thought that it was a regular customer. Thus, it was not considered in planning the order of the restoration process.

Additionally, municipalities rely on hard copies of their customer information system and use paper maps to locate the customers who may need help. In the workshops, it was

revealed that information about the location of elderly people and home-care patients is scattered across multiple maps and data bases. That information is combined with inaccurate information about the outages from DSOs' web pages.

MNOs are facing problems with information about the need for backup power during disturbances in electricity networks. In some cases, two operators have brought portable backup power to same mobile network base stations.

3.5 Information needs of stakeholders

The information needs of all stakeholders were primary questions in the survey, interviews and cooperative workshops done in this study. In the survey, several use cases for information exchange were presented and the DSOs' opinion of their importance was asked. Further, in the interview, the question was what information the stakeholders would need during major disturbances. The main result was that information needs vary based on the role of the stakeholder. The main needs are presented in the following list.

DSOs need information about:

- Where the outage is located
- Cause of the outage
- How electricity can be restored
- Whether mobile network coverage exists in the area
- How the actions of the other organizations affect the restoration process
- Weather forecast
- How long mobile network base stations can operate without electricity
- Whether the customer or stakeholder is using backup power
- Where evacuation are planned to carried out

Fire and rescue services need information about:

- Wheter there is disturbance in their operation area
- Which DSOs operate in specific locations
- People who may be in danger
- Plans by the municipality to evacuate
- Weather forecasts

Municipalities need information about:

- Any home-care patients or elderly people in the disturbance area
- Whether a disturbance exists in their operation area or in neighboring municipalities

- People who need help in obtaining food, water or shelter
- Patients with safety phones, who do not have electricity or mobile coverage
- Weather forecasts

In the survey, the DSOs wished that information about major disturbances would be delivered especially to public authorities. In addition, the storm and snow forecasts were highly important. Common for all stakeholders was that they need bidirectional functions of systems they use for information exchange. For example, fire and rescue services need to inform the local DSO if a tree has fallen on power lines. Additionally, municipalities want to inform home-care patients and volunteer rescue groups about the situation.

The main difference in the responses was related to the question of how widely the situation should be viewed in a situation awareness system. The fire and rescue services want to focus only for their operating area, while municipalities and DSOs want to see the situation more widely.

According to interviews, the municipalities have many problems with information exchange during disturbances. They would greatly benefit from a system that combines their critical customers, like elderly people or home-care patients, into the same view of the disturbance situation. Seeing the customers on a map instead of the present registers would improve their perception of the scale of the situation.

A need to combine information about the situations of mobile networks and electricity networks emerged in the interviews and workshops of this study. Because of the interdependencies (presented in chapter 2.3.1), the information about mobile networks is important for DSOs. Additionally, public authorities can use the information about mobile networks to locate the people whose safety phones or emergency buttons may not be working.

4 Situation awareness system for major disturbances in electricity networks

This chapter introduces the situation awareness system developed in this study. In addition, the design process is described. Further, two case studies done in Finland are presented and analyzed. This chapter summarizes the results of the publications II-VIII.

4.1 Design process

Based on Panteli et al. (2015) the design process of an SA system for adequate situation awareness begins with determining the SA requirements. Available technologies should be used and the design of the user interface should be user-friendly. Thus, the sources of operator errors can be prevented. When the human factors and ergonomics are included in the interface design, the capabilities and requirements of the user can be considered in information integration. The next step is to develop an SA enhancement plan. To implement this plan, the achieved level of SA needs to be assessed. This can be conducted through use of a simulator for operators. The analysis of these simulations can then be used to evaluate the operators' performance. Finally the SA enhancement plan can be implemented by using the input of the SA assessment. The process should have an infinite loop, because to achieve an adequate level of SA the control center applications need to be continuously upgraded. (Panteli et al. 2015).

In this study, a demonstration of a situation awareness system for disturbances in electricity networks was developed. One commonly used design process that is linked to Endsley's SA theory would have been Joint Division of Laboratories (JDL) data fusion model (Tadda et al. 2010, Steinberg et al. 1999). However, it is highly data centric method and bases on sensors to produce data. In this study, the focus is in information needs of the stakeholders in disturbances of electricity networks. In this case, there is need for subjective view to decide e.g. what is the critical time that customer can be without electricity. Thus, the design process was executed similarly to an action design research method (Sein et al. 2011). It is a research method that involves the perspective from users in ongoing use in context in addition to theoretical aspects. The method introduces two challenges: 1) a problem situation encountered in a specific organizational setting is addressed by intervening and evaluating; and 2) an IT artifact that addresses the class of problems typified by the encountered situation is constructed and evaluated. The method is similar to the design process of Panteli et al. (2015).

In this method, the research process is carried out as an iterative process in a target

environment. This phase includes the building of the IT artifact, intervention in the organization, and evaluation. In this study, the Organization-Dominant Building, Intervention and Organization (BIE) process was chosen, because it is suitable for studying the decision-making situations in organizations. In this method, organizational intervention is the primary source of innovation. During the iterations, the existing ideas and assumptions about the artifact's use context from the organizational participants' is challenged by researchers. An assessment of the artifact and design principles that it represents are conducted at the end of every iteration. The generic schema for the process is illustrated in Figure 4.1. (Sein et al. 2011).

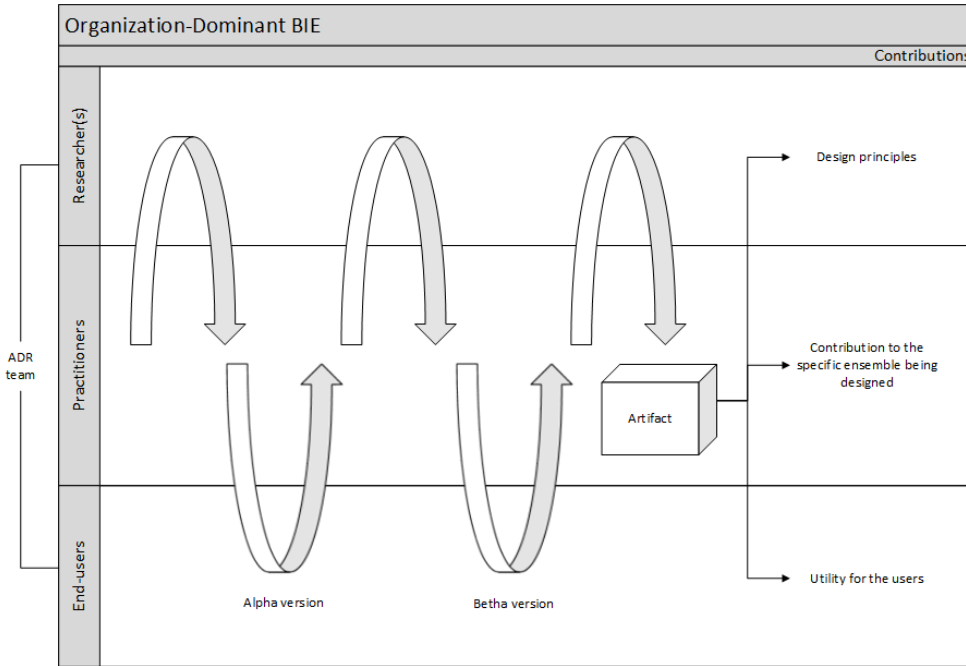


Figure 4.1: The generic schema for Organization-Dominant BIE (Sein et al. 2011).

As in the action design research, the SA system design process was iterative in this study. A functionality specification was conducted based on the results of the workshops and survey carried out by this study. Based on the specification, a concept for the system was created. The concept was then used to develop three different versions of the demonstrations of the system. Each version of the demonstration was presented to possible users of the system and evaluated by different methods. Both the concept and the versions of the demonstration were improved based on the results of the evaluations. The design process is illustrated in Figure 4.2.

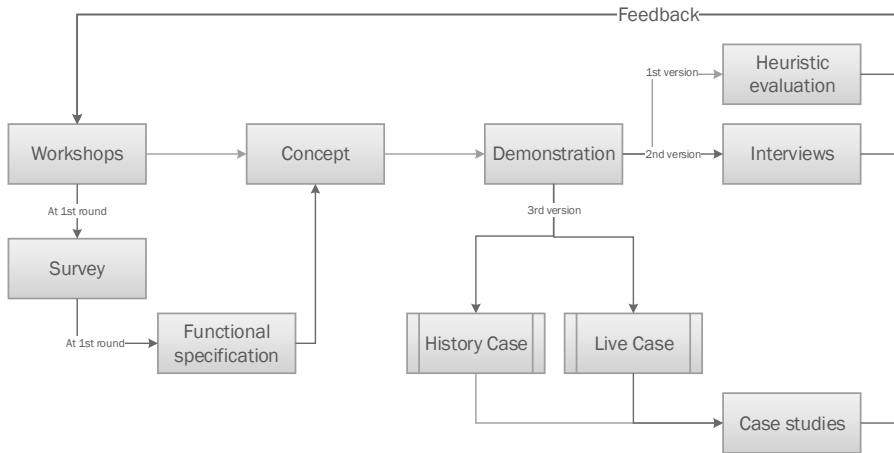


Figure 4.2: The design process of the SA system in this study.

The user interface of the system was designed by using the design principles of Endsley (described in (Endsley et al. 2011)). Endsley summarizes eight principle for designing a situation awareness system. The principles are following:

- Principle 1: Organize information around goals.
- Principle 2: Present Level 2 information directly – Support comprehension.
- Principle 3: Provide assistance for Level 3 SA projections.
- Principle 4: Support global SA.
- Principle 5: Support trade-offs between goal-driven and data-driven processing.
- Principle 6: Make critical cues for schema activation salient.
- Principle 7: Take advantage of parallel processing capabilities.
- Principle 8: Use information filtering carefully.

Especially the principles two to four were the main focus in this study, because of the complex nature of the disturbances of electricity networks.

Because the user interface plays an important part of creating the situation awareness for users, the system was tested by usability methods. After this testing, the system was further developed. The latest version of the demonstration was evaluated using two case studies. Different parts of the design process are presented and their results analyzed in the following sections.

4.2 Results of the functionality specification

To study the functionalities of an SA system, several use cases for SA system was presented and the importance of the use cases were asked in a survey done among the DSOs (presented in publication I and II). Importance of the use cases was rated with numbers from 1 (not at all important) to 5 (highly important).

Table 4.1: Use cases and results of survey

	Use case	Average	Median
C1	Information about the critical outage time of the base stations of the mobile networks for DSO.	4.25	5.00
C2	Information about the reserve power of the customer for DSO.	3.47	4.00
C3	Information about events that are highly dependent on electricity (e.g. festival, sports event) for DSO.	3.49	4.00
C4	Storm and snowfall forecasts for DSO.	4.55	5.00
C5	Information about water level for DSO when a flood risk is remarkable.	3.76	4.00
C6	Information about long lasting and widespread disturbance for the emergency call center, fire and rescue service, police etc.	4.57	5.00
C7	Information about widespread and probably long lasting disturbance for customer.	3.59	4.00
C8	Forecast information about duration of the disturbance for fire and rescue service and municipalities to support the decision making about evacuation.	4.08	4.00
C9	Information for authority of special health care, if an home care patient, which is highly dependent on electricity experiences an outage.	3.88	4.00
C10	Information about status and location of units of the fire and rescue service for DSO in order to optimize disturbance management.	3.32	3.50
C11	Information for DSO, about areas that arrange a manual water supply.	3.20	3.00
C12	Information about locations where the evacuation is planned or carried out for DSO.	3.71	4.00

Results of the use cases are presented in (in table 4.1) Based on the survey, the most important use cases were C6 "*Information about long lasting and widespread disturbance for the emergency call center, fire and rescue service, police etc.*" (with average of 4.57) and C4 "*Storm and snowfall forecast for DSO*" (with average of 4.55).

The UML method (Chonoloes et al. 2011) was used to determine the functionalities of the situation awareness system. The results of the survey and the workshops were used to recognize the main functionalities. The structure of the system was described using class diagrams and the users' interactions with the system were studied using use case diagrams. Based on the specification, the main functionalities for the system were following:

- Registration to the system
- Classification of users
- Sign in
- Inform the system about the criticality of the site
- Define the critical time
- Study the criticality information

- Give the information about critical sites to DSOs and authorities in normal situations
- Input information about outages to the system
- Present outages on a map to every registered user
- Present critical sites on map to DSOs and authorities
- Create the warning message
- Send the warning message to sites and authorities

Based on the specification, the users of the system were a customers of DSOs, authorities and DSOs. The customers of DSOs were divided into two groups; a regular customer and a critical customer. The customer can receive warning messages and see the outage situation of their own address on the map. Additionally, the critical customer can see all their critical sites on the map and use the "defining the critical time" function. The authorities and DSOs can study the criticality information of all sites that are in the system and receive warning messages about the critical sites. The DSOs use the function "input information about the outage to the system." The information structure of the system is illustrated in Figure 4.3.

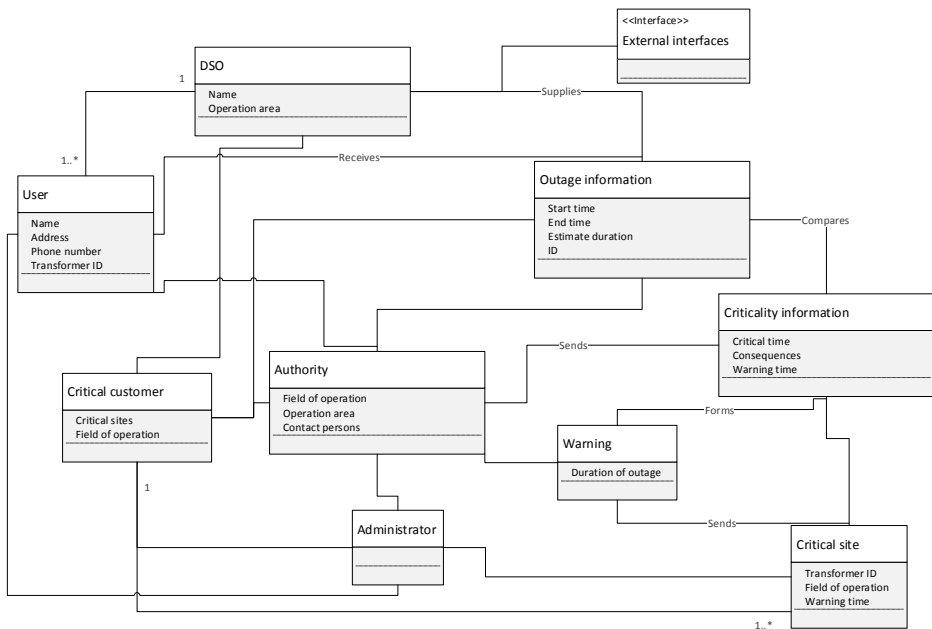


Figure 4.3: A class diagram of the information structure of the system.

The system has an external interface for information from outside. The main use for that interface is the information about electricity network outages. Additionally, it can be used for other useful information like weather forecasts, determining resources available from contractors or traffic information.

Using the system for simulation and network design purposes were included in the specification. A simulation can be conducted by changing the live input of the outages to information simulated for a training purpose. In this case, DSOs and authorities can practice their processes in place for disturbances. In addition, these simulated disturbances can be used in network design by detecting areas that are most important for the functioning of the electricity network or most important for customers. Further, the network can be improved in those areas to decrease consequences.

As a part of the specification, the use rate was evaluated. The system is used mainly during disturbance situations. In those cases, there can be a huge number of users. At the specification, the use rate was estimated roughly based on the number of the main stakeholders (in table 4.2) and main critical customers (in table 4.3) in Finland. These estimations do not consider that one stakeholder or customer can have several users. Additionally, if the system is offered for normal customers of DSOs, the number of users can increase to hundreds of thousands during major disturbances. Thus, the system must be designed to handle a large number of users to ensure its functioning in the worst cases.

Table 4.2: Number of the main stakeholders

Stakeholder	Number
DSO	92
Municipalities	336
Fire and rescue services	22
Maintenance companies	150
Police stations	24
Emergency centers	6
Ministry of the interior	1
Transmission operator	1
Emergency center of the Prime minister's office	1
Total (approximately)	650

Table 4.3: Number of the main critical customers

Critical customer	Number
Hospital districts	92
Water utilities	88
Sewer systems	73
Mobile network operators	3
Total (approximately)	200

Based on the functionality specification, there are some challenges with executing the usability and the safety of the system. Thus, to be used during disturbances, the electricity supply for the system must be secured. Additionally, the functionality of the system, in case of telecommunication disruption or equipment failure must be secured. One challenge in developing the system is that some information can be delicate or controlled

by legislation due to privacy concerns. Thus, cyber security of the system is important. Further, the user interface must be easy to use, because the system is used mainly in highly stressful situations, where multiple systems are used simultaneously. Some issues were left open at the functionality specification. One main problem that was not defined was "Who is the main user or the technical administrator of the system?".

The functionality specification was conducted only in the beginning of the design process. However, some functionalities were added in later in the design process based on workshops and interviews. List of the added functionalities are the following:

- Input disruptions in mobile network coverage
- Present disruptions in mobile network coverage on map
- Input tasks of fire and rescue services
- Present tasks of fire and rescue services on map
- Input traffic information
- Present traffic information on map
- Add information layers
- Add municipality lines
- Customize the view for the user
- Input history data
- Present time line in history mode
- Present history data based on time in history mode

Some of the main functionalities added afterwards were history mode functions, like inputting data about previous outages in the system, and presenting it based on the time stamp of the outage.

4.3 Concept for the SA system

Based on the results of the survey, workshops, functional specification and interviews, a concept for the situation awareness system was developed. It describes the main features of a situation awareness system for disturbances in electricity networks. Different versions of the concept were created during the design process, based on the newest results of the workshops and interviews. The first version of the concept after the functional specification (illustrated in Figure 4.4) presented the user groups and information flow in the SA system.

The users of the SA system were classified into three different levels in the first concept based on the functionality specification. In this concept, the critical users were divided into two groups, based on whether the critical user owned multiple critical sites or whether it was only the user's own site. Further, there was an open or public part of the system, in which the regular customers of the DSO could receive warnings of outages at their own

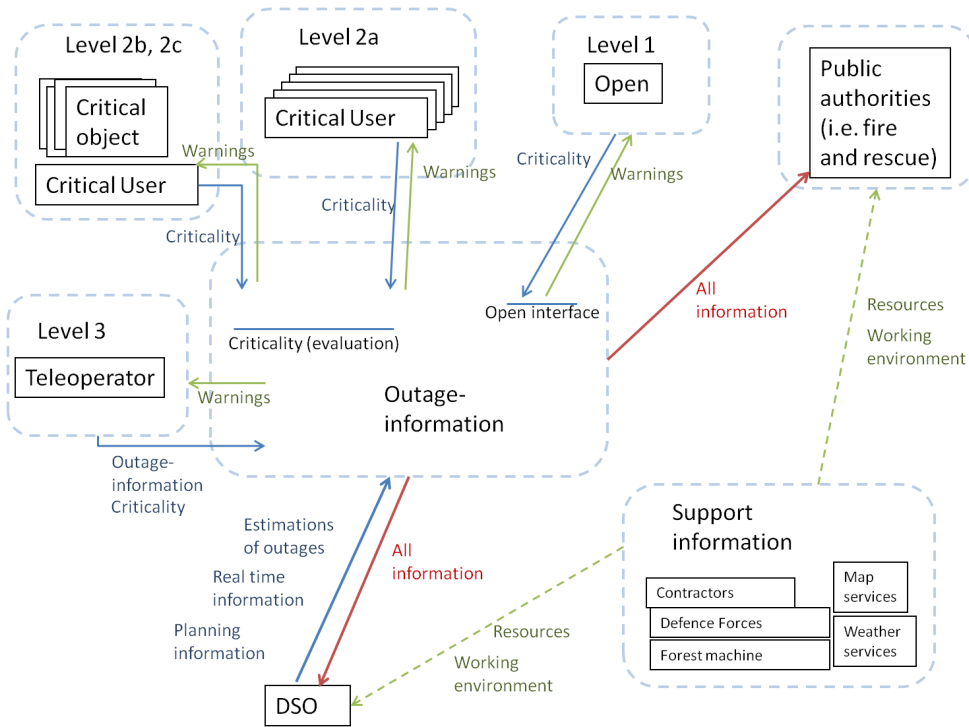


Figure 4.4: The first concept for the SA system.

location. This concept did not specify a database for critical information. Information about critical sites was only added to the information flow of the system.

Further, the second version of the concept (illustrated in Figure 4.5, consisted of a real-time situation awareness part and risk management part, which covered the development of electricity networks and preparedness.

This version of the concept was based on the criticality database, which contained all information about critical customers or sites. In the workshops carried out by this study, it was clarified that there is a need for information about customers who are highly dependent on electricity. These critical customers can be, for example, hospitals, home-care patients, patients with respirator living at home and different critical infrastructures. In the concept, this information was gathered into a manually-updated static database. In addition to disturbance management, the information about critical sites could be used for risk analysis. Based on the concept, the risk analysis part could be used for network development and developing the preparedness of the stakeholders.

The concept was developed further based on the results of the interviews. The main results were that the fire and rescue services and municipalities need information from all DSOs operating in their area in a simple view. All stakeholders highlighted that there should be only one system where all relevant information can be found. They were concerned that the work-load for operators should not increase.

In the newest version of the concept, all information related to the disturbance is gathered into one system. The structure of the system is illustrated in Figure 4.6). The information can be, for example, electricity network outages, mobile network coverage, weather

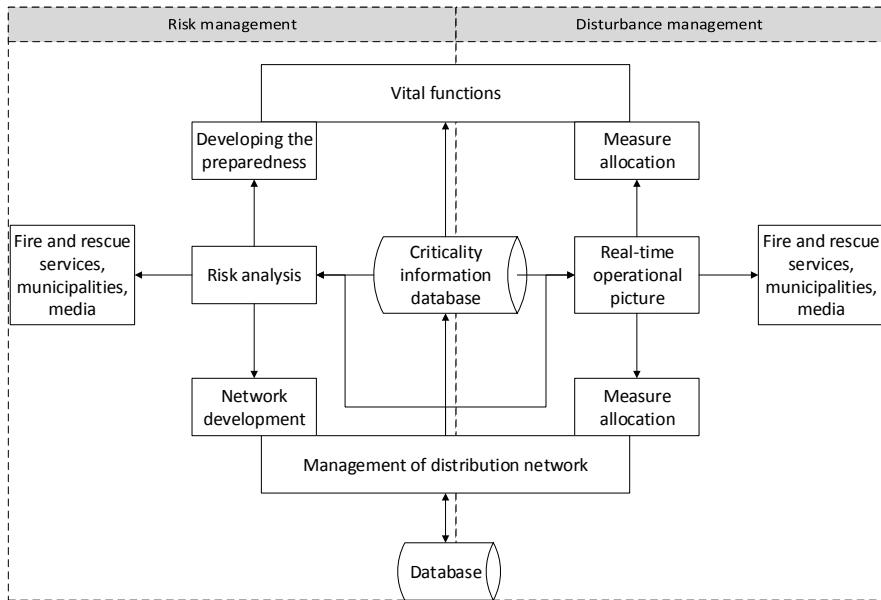


Figure 4.5: The second version of the concept.

forecasts and traffic reports. The concept allows feeding information from multiple DSOs and mobile network operators into the system. The information is presented via web-based user interface, which can be used both for disturbance management and risk management. Unlike the previous concept, this version focuses mainly on real-time operation.

The concept covers electricity and mobile network disturbances and can be extended to cover other critical infrastructures, such as water supply. In this concept, the users of the system are DSOs, fire and rescue services, mobile network operators and municipalities. However, other stakeholders, such as police can be added to the system if needed.

4.3.1 Criticality database

One of the main elements in the latest concepts is a database for criticality information of customers. This function is for so-called critical customers who are highly dependent on the electricity supply or who have sites that are highly dependent on the electricity supply. These sites can be critical infrastructures, such as water pumping stations, base stations of mobile networks or other sites that are highly dependent on the electricity supply, like special health-care patients, retirement homes or nursing homes.

In this concept, users are responsible for updating the information about their sites. The information can be added to the system when creating the site or manually updated later. In addition to site's location, there is information about "critical time", a time period that the site can manage without electricity, to prevent severe consequences to people or property. Further, there is the information on how bad the consequences will be if the critical time is exceeded.

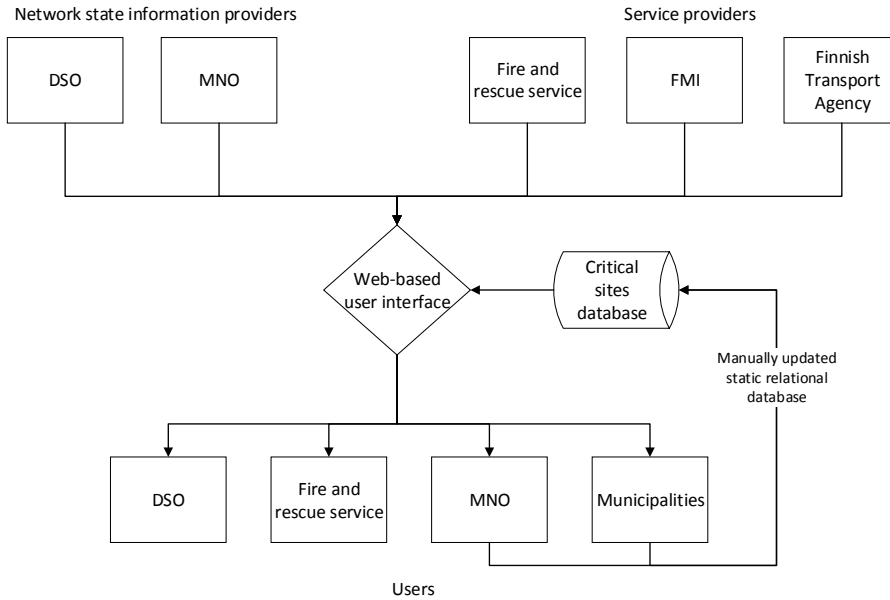


Figure 4.6: The structure of the SA system.

The DSOs and authorities can see all the critical sites from the system. Thus, DSOs are able to consider the critical sites while planning the order of the restoration process and further for the network development. In addition, the authorities can use the information to plan their own processes; for example, they could consider these sites in evacuation planning.

4.3.2 Filtering information

The concept includes a filtering function to avoid information overload. Additionally, with this function, information from the different DSOs can be combined to the same view. The function enables filtering of the information from the users' own operating area (Figure 4.7). For example, in the operating area of the municipality 1, there are two DSOs operating. The municipality can filter the information from both DSOs into the same view so that only outages from the area of municipality 1 are shown.

Similar filtering is possible for fire and rescue service operating areas. Additionally, the filtering function can be used for all information, like weather forecasts.

4.4 Demonstration of the system

Based on the concepts, different versions of the demonstration of an SA system were developed. Several versions of the demonstration were presented to the stakeholders of the disturbances in electricity networks to get feedback and improve the system. Three different versions of the demonstration were implemented. The first version of the demonstration was evaluated by a heuristic evaluation and the second version was studied

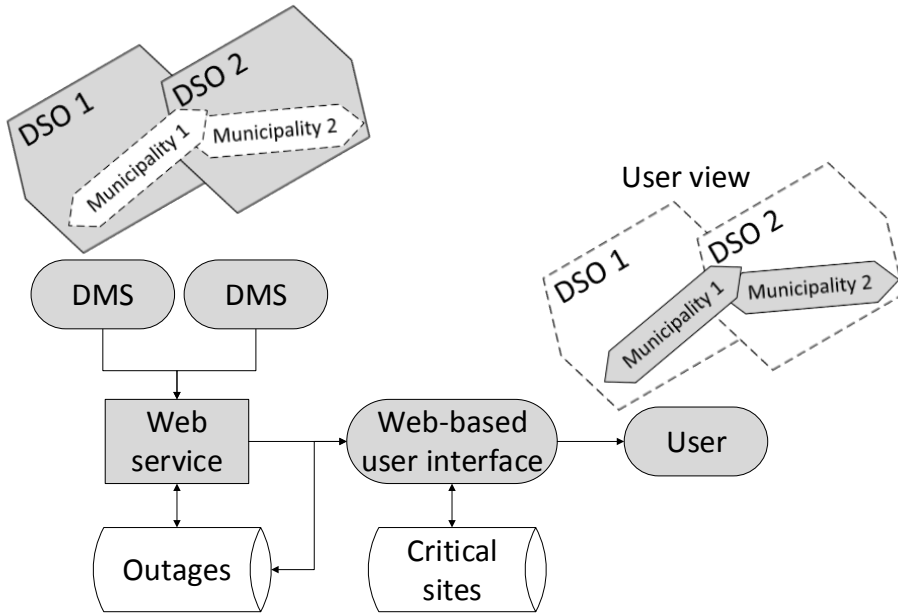


Figure 4.7: Filtering function of the SA system.

via semi-structured interviews. All three versions were evaluated in workshops of this study. Different versions of the demonstration and the analysis of the evaluations are presented in the following sections.

4.4.1 The first version

Based on the first presented concept, the demonstration of the SA system was developed. The first version of the demonstration (illustrated in Figure 4.8) was built on Google Maps. It had a situation awareness mode, which presented the outage situation; and an edit mode, which could be applied to change information about the user or the critical sites of the user. This version presented electricity networks outages, tasks of rescue services, weather forecasts, traffic reports and critical customers. The survey showed that, the DSOs were concerned that the incompatibility between information systems would be a challenge in developing an SA system. This was considered in developing the system by using the information from existing systems. Only the outages of Version One were generated manually to the database for demonstration purposes. However, the file format of the outages was same as in existing systems.

The demonstration presented all outages of the electricity distribution network at a transformer level. Additionally, one of the main features of the demonstration was the criticality database. Transformers without electricity were presented with a gray lamp symbol. The critical sites that each user was responsible for were presented in the view. Critical sites were presented with different symbols according the reason for their criticality. The symbol was framed by a traffic light color based on time left in their critical time period or if the time had been exceeded. More information about critical

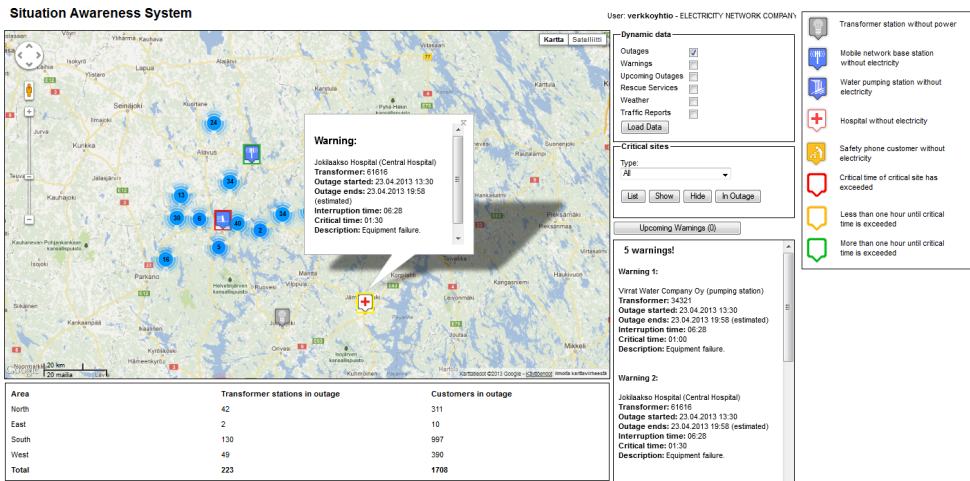


Figure 4.8: The user interface of the first demonstration.

sites and outages appeared by clicking the icons in the map (illustrated in Figure 4.9).

Blue and red clusters in the maps combined several outages to minimize the number of information in the view. The number in the middle of the cluster showed the number of transformers without electricity. If there were critical customers in the outage area, the cluster was red. In addition to the map, there was a table that presented numbers of the transformers and number of the customers, who have outages. In the lower right corner, there was a list of the warnings, which presented information about outages and critical sites.

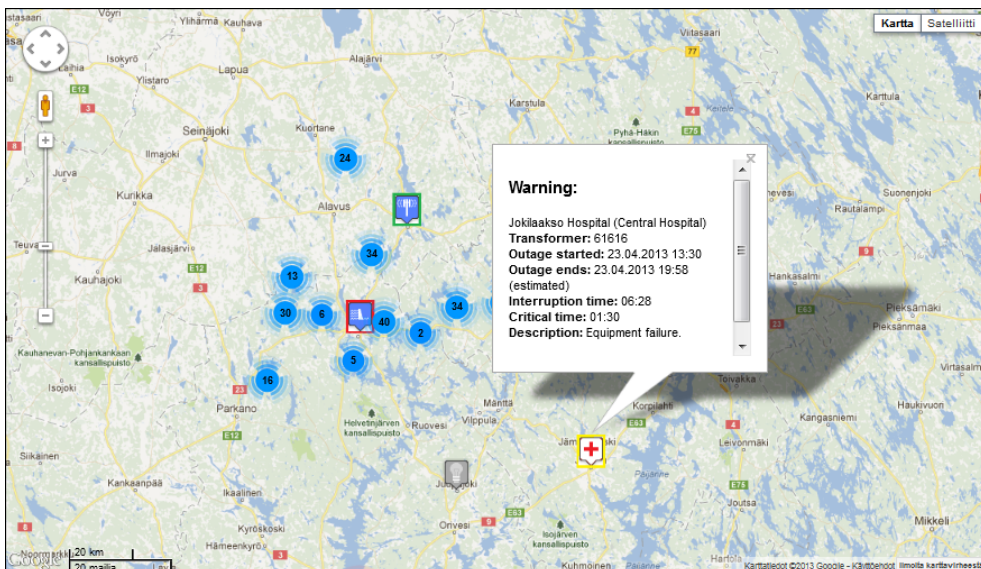


Figure 4.9: The close view of the user interface.

4.4.2 Results and the analysis of the heuristic evaluation

A heuristic evaluation based on Nielsen's (1993) method was conducted as a part of the design process of the demonstration. Results for every principle of the heuristic evaluation are listed in Tables 4.4 and 4.5. The main results were that the first version of the demonstration had a clear user interface and it was easy to use without a manual or training. Additionally, the system did not significantly increase the user's memory load. The overall consistency was good, despite some minor consistency issues. Still, there were multiple deficiencies that needed to be fixed (e.g., there was no manual for the system and there was a lack of error messages).

Based on the heuristic evaluation, the main demand for improvement was to add personalization to the system. When multiple organizations are using the system, they may want to highlight different elements of the system. Another important update request was to finish the appearance of the user interface with softer colors and rounder corners. Additionally, the colors of the buttons should have been chosen more carefully, so that it is clear which window the user is using. One main problem with the feedback on the system was the ability to notice whether the map has been updated or not. This could be fixed by adding a time stamp in the bottom corner of the map to show the most recent time it was updated. There were only two error messages on the system. More should have been provided—there should be an error message if an update fails. Additionally, the place of the error messages needed to be improved—it should not have been in a separate window like it was in this version of the demonstration. The main conclusion of the heuristic evaluation was that the first version of the system was still incomplete and needed to be developed further.

Table 4.4: Results of the heuristic evaluation a)

Principle	Success	Deficit
Simple and natural dialogue	View is simple and light.	Not everything fits in the view at the same time.
	There are only three main elements. Most important element, the map is easy to notice.	Symbol explanations takes too much room.
	Clusters minimize the number of information.	
	used colors clearly express the criticality.	The button colors are confusing.
Terminology	Easy to understand even when user is not a specialist.	Quite specific professional terminology is used.
	Symbols are simple and commonly known.	
	The criticality of the sites is presented clearly, by the size of the symbol and the state of the critical time, with traffic lights.	
	The system uses commonly-used radio buttons to add information to the map.	
Minimizing the users' memory load	Choosing views, that the user wants is easy by clicking boxes near the map.	
	The user interface does not need time to learn. It is easy to learn by trying different elements of the system.	
	The elements that can be clicked are presented so that they can be recognized to be dynamic.	
	All symbols are explained under the map. Thus, the user does not have to remember them.	
Consistency	The information about outages is presented clearly, because only the customers without electricity are shown.	The system does not work well with every web browser. Some functions look different and some do not work at all when using different browsers.
	The user interface works like related map-based systems which adds consistency to it.	“Situation Awareness” and “Edit Mode” buttons are presented with strong colors. That makes them dominate the view.
	Different elements of the system are gathered to boxes, so that there is one subject always in the same box.	The tables under the map look different in “Situation Mode” and “Edit Mode.”
		Some of the info windows disappear when clicking them and some when the mouse is hovering over the icon. In “Edit Mode,” the info window has scrolling ability.
Feedback	New information uploads quickly.	Map updates quite rarely and it is hard to see if it has already updated.

Table 4.5: Results of the heuristic evaluation b)

Principle	Success	Deficit
Exits	Moving between different views is handled with buttons “Situation Awareness” and “Edit Mode.” Different views of the map are easy to change by clicking boxes next to the map.	
	Logout is placed clearly.	Logout could be marked as a button and not a link like it is now.
Shortcuts	Shortcuts are conducted so that there is possibility to hide symbol explanations.	Hiding is not marked clearly.
	In the map, there are chances to zoom with mouse scrolling or with the zoom marks in the map.	When logging in, the cursor is not located in the text box. There is no possibility to personalize the view.
Error messages	Error messages are conducted clearly in the system.	There are only a few error messages in the system. More should be available.
	When using an incorrect user identification, the error message explains why login did not work.	A new error page is opened and you have to go back to the previous page to try to login again.
Preventing errors	There are no chances to cause the system to be stuck by using it incorrectly.	
	If user makes mistakes with inputting user identification, it is not possible to continue before giving the right information. The user interface is so easy to use, that the possibility of errors is small even without reading the directions or in problem situations.	
Help and documentation	There is an explanation for all symbols used in the map at the bottom of the page and the system is quite easy to use even without a manual.	Because the system is still a demonstration, there is no documentation with directions.
		The system does not provide any instructions at all while using it.

4.4.3 The second version

Based on the results of the heuristic analysis, the user interface was cleaned up and harmonized. The view was made softer by removing the box frames and by lightening the colors (see Figure 4.10). Additionally, the presented information layers could be chosen via an icon in the upper right corner of the map, instead of the box next to it, as in previous version. Thus, there was more room for the map and the warning list. To improve the user experience of the demonstration, the user interface was fitted to screen size. Thus, there was no need to scroll.

Further, the map was changed to open source (Open Street map), because the free version of Google Maps had restrictions on their license of use. The main new character was the filtering function and the municipality borderlines added on the map. With this function (illustrated in Figure 4.11), municipalities and fire and rescue services could observe their operating area.

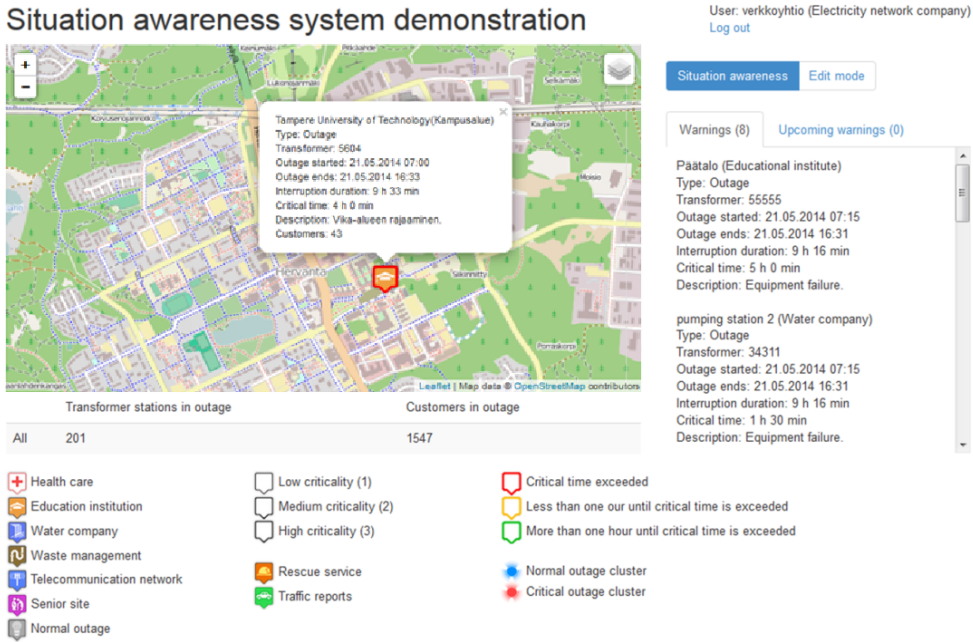


Figure 4.10: The user interface of the second version of the demonstration.

In this version, the outage clusters were replaced by coloring the municipality that has the outage, in red, like in Figure 4.11. In this case, the individual outages are easier to recognize than in the previous version.

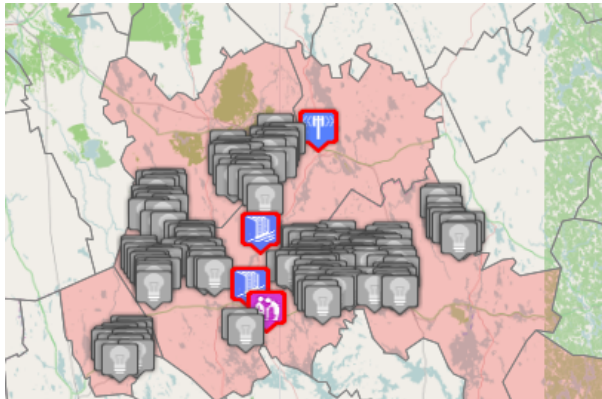


Figure 4.11: Close view of the map in demonstration.

4.4.4 Results and analysis of the interviews

The second version of the demonstration was presented in the interviews to the representative of a fire and rescue service and representatives of a municipality to get feedback from them as possible users of the situation awareness system.

As a main result, the interviewees thought that this kind of system would be important to them and they would use it in their operations. The main information that the demonstration gave was the information on how widespread the disturbances were. Additionally, the fire and rescue service thought that the municipality borders in the map were important. Overall, the simplicity of the user interface was highlighted as a good feature. The information about the critical sites was one of the most useful pieces of information that the demonstration presented.

Some inconsistency with the answers occurred, regarding which information should be presented on the map, and which areas should be shown on the map. For the fire and rescue service, it was important that they could see their operating area at the first sight when opening the system. They would want to be able to see the situation in the whole country only when needed. On the contrary, the municipality desired to see a wider area to achieve an overall awareness of the disturbance.

The main improvement idea from the interviews was a two-way function. There should be a possibility to send information for DSOs, (e.g., information about a tree fallen on electricity lines). Additionally, they wanted more information about critical sites, like information on whether the site has backup power. Further, information about the customers of the municipality (e.g., disabled people and elderly people) should be added to the system. In addition, they would need information about service points where the municipality offers evacuation sites or food for citizens during disturbances. One main addition that the interviewees wanted was the information about disturbances in mobile networks on the map.

Other development ideas concerned the user interface. The interviewees thought that a possibility to open the map to a whole window would be important. The fire and rescue service preferred the information about outages as a line on map, instead of the transformer symbols. Additionally, they wanted more efficient colors for outages (e.g., red and yellow).

Overall, the interviewees thought that a situation awareness system would improve their operations during disturbances in electricity networks. Based on the interviews, the simplicity of using the system and adding their own sites to system should be the main development targets of the demonstration.

4.4.5 The third version

The demonstration was developed further based on the results of the interviews. In the latest version (user interface illustrated in Figure 4.12), the view is personalized according to the needs of the user groups. The personalization was done to reduce the information overload of the user. As the interviewees wished, this version automatically filters the map to the right operating area. Additionally, there is a functionality to change the starting view whenever needed. The information layers on the map can be defined while implementing the system. While using the system, the layers can be activated or deactivated from the menu in the upper-right corner of the map. In addition, the user can add their own information layers to map; for example, a municipality can choose a layer of all citizens older than 75 years. The information can be fetched from the users' own information system, if necessary integration is done. However, in this version it was implemented by updating the information manually to the database.

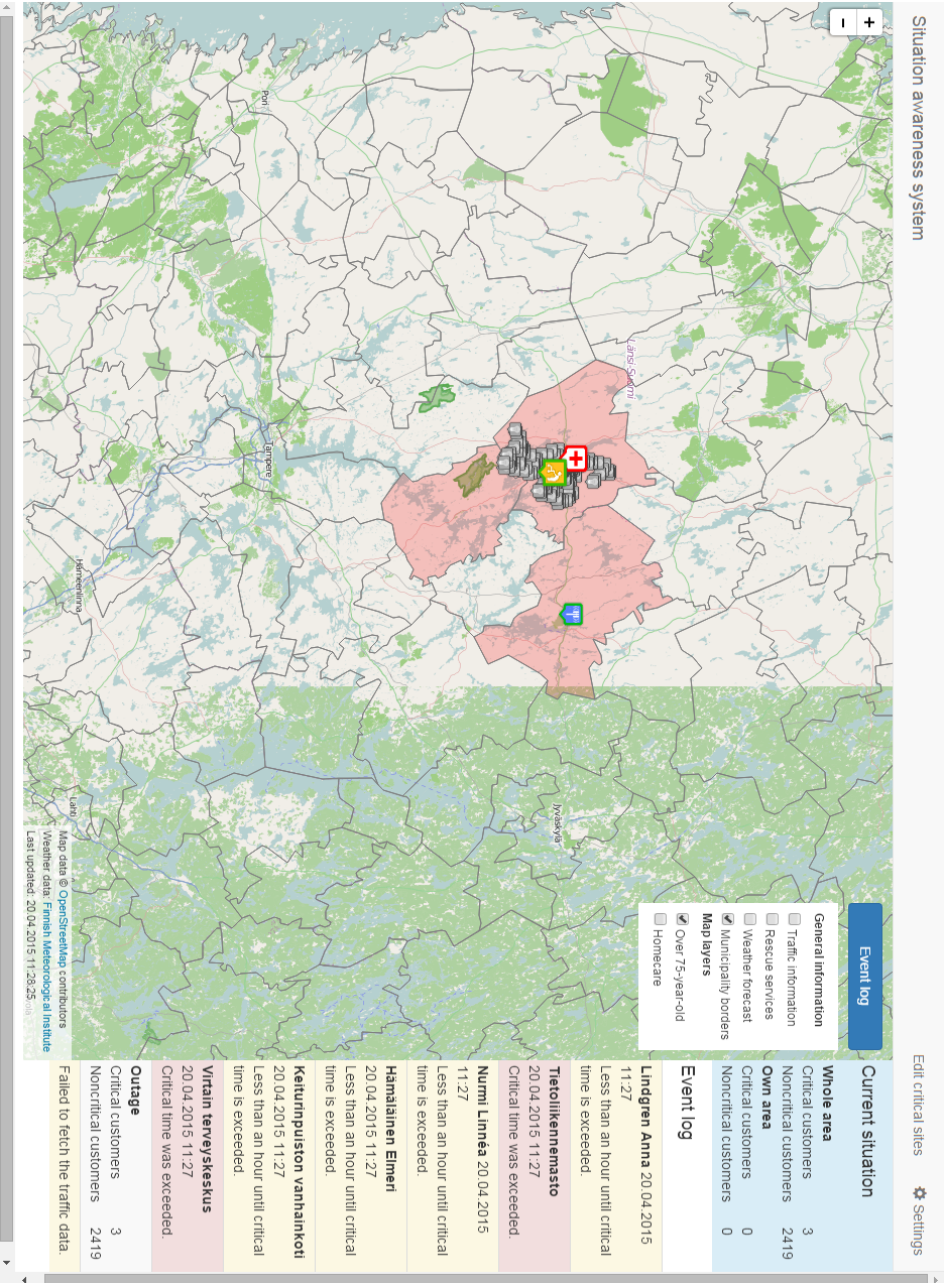


Figure 4.12: User interface of the third version of the demonstration.

The main target of the development in this phase was to improve the simplicity of the user interface. In the interviews, the main concern was that the system should be simple to use. To improve the visibility of the critical sites, the size of transformer symbols was decreased and the color changed to gray (illustrated in Figure 4.13). To process the information further, the level of criticality is presented by different sizes (e.g., a central hospital has a bigger symbol than a local health center). The new version of the demonstration has a larger map view.

The current situation of the disturbance, like the number of critical and normal customers without electricity was presented as a summary in the upper-right corner of the view. To simplify the view, the list of warnings was changed to an event log next to the map. Traffic light colors were used on the event list to indicate whether the critical time of the critical sites has been exceeded or would be exceeded soon (in Figure 4.12).

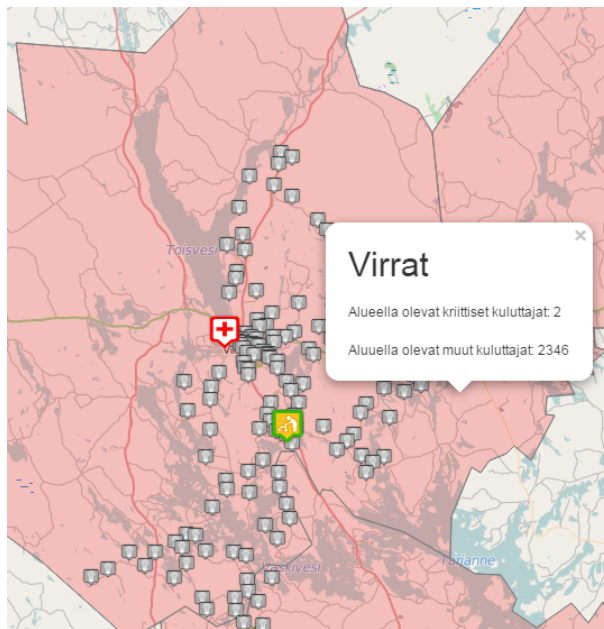


Figure 4.13: Critical sites are presented with larger symbols than transformers.

The main improvement to former versions is that the new demonstration has the coverage areas of mobile networks. The data comes from a mobile network operator and is processed so that the users see only areas that do not have any mobile coverage (illustrated in Figure 4.14). Additionally, there is an option to show the areas that have mobile network coverage. The latter information can be used to find the mobile network base stations that are using the backup power, by comparing the coverage information to outages in the electricity network.

4.5 Case studies

The demonstration was used to conduct two case studies; a historical data case and a live demonstration. The third version of the demonstration was used as a base in these studies. The case studies were done to evaluate the system and the results of the studies

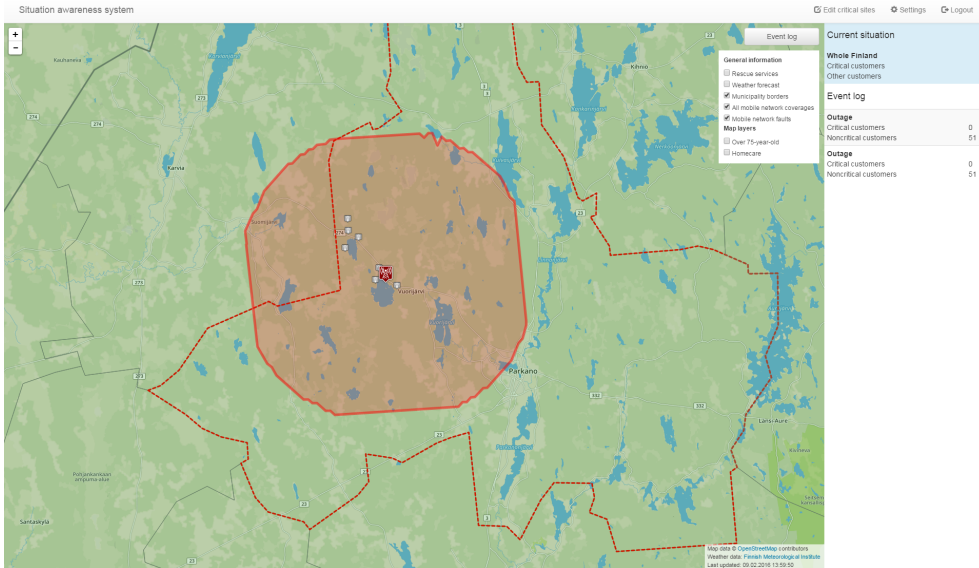


Figure 4.14: Mobile network disruption shown in demonstration.

were presented to different stakeholders to get feedback and to improve the developed SA system.

4.5.1 Historical data case - Finland

The historical data case is described more precisely in publication VI. The case study was conducted to evaluate the use of the developed demonstration in improving the restoration process of the electricity and mobile networks. Additionally, the interdependencies of both networks were studied with this case.

A disturbance that occurred in Finland was studied using the demonstration. The disturbance was caused by a storm. Thus, it expanded gradually across the electricity network. A post-mortem analysis of the outage was conducted. Information about the case was received from one DSO, MNO and from a field communication service provider. The provided information were the transformer status information from DSO, configuration and status information about the mobile network base stations from MNO and the communication link statuses of the switches in the electricity network from the field communication service provider. Some functionalities, like presenting a time-line and presenting data based on the time, were added to demonstration to enable the historical case study. The Figure 4.15 illustrates the user interface of the historical case and shows the explanations of the symbols. The location of the disturbance, the map layer and time information were removed because of a non-disclosure agreement with the cooperating MNO.

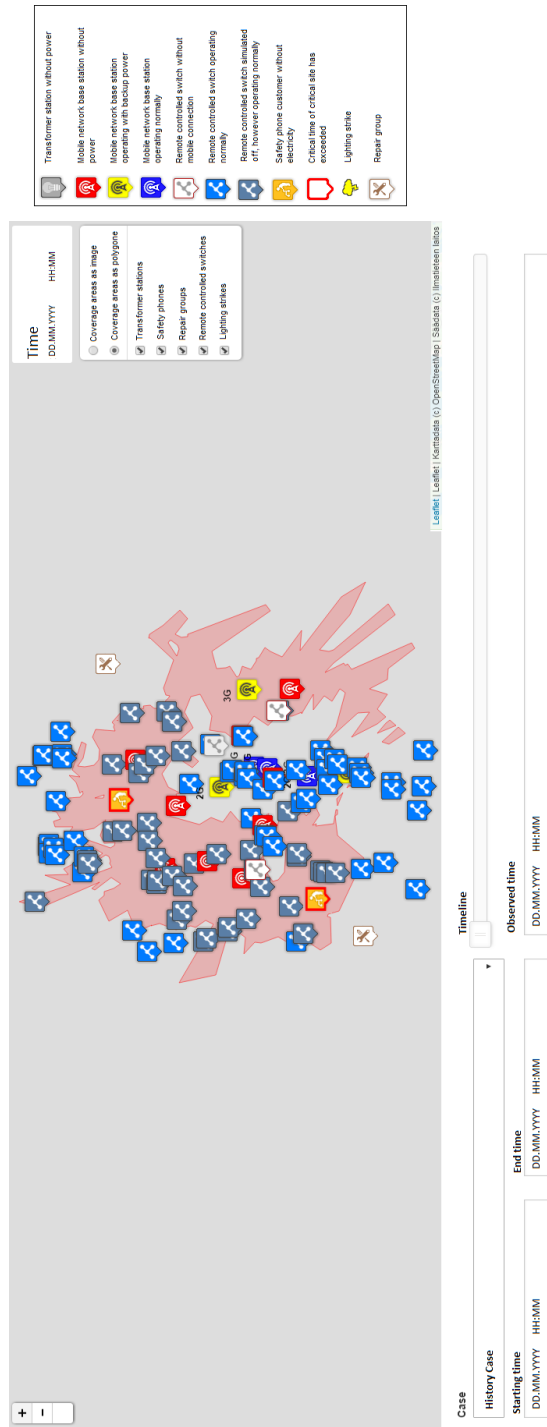


Figure 4.15: The user interface of the historical case and explanation of the symbols.

The MNO provided information about whether the base station was active or not. Based on this data, the demonstration simulated the coverage areas of each base station. The data was visualized on the map with the coverage areas and the status information of the base stations. There was no information about whether the base station was supplied by the electricity network or by the backup battery. Thus, a simple model was used: if the nearest transformer was affected by the outage, the base station was being supplied by the backup battery. Further, the MNO wanted information about lightning strikes in the area during the disturbance (in Figure 4.16). This data was added to the system based on the open data given by weather service.

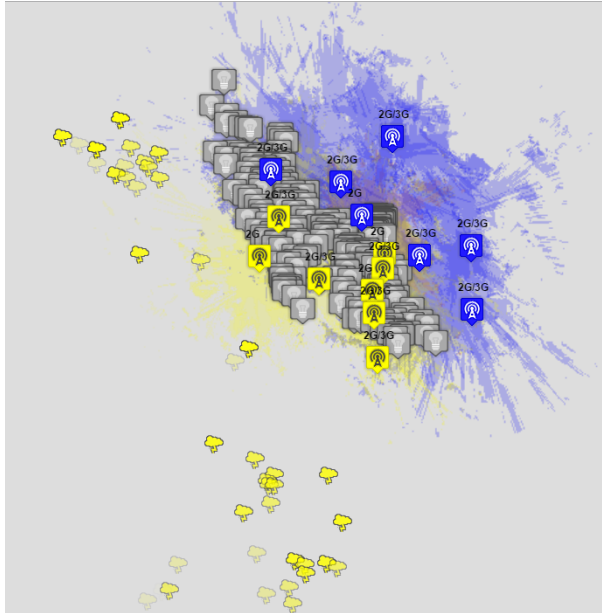


Figure 4.16: Lighting data from the historical case.

The status information about the communication connection of the remote-controlled switches in electricity network was provided by the field communication service provider. The status of the communication connection was either on or off. If the connection was on, the packet loss was 0%. If the connection was off, the packet loss was 100%. Further, a modeled status for the communication connection of each switch was calculated based on its location in the coverage area using the modeled coverage areas. The status information from the service provider was compared with the modeled status information. Both real and modeled statuses were displayed with the demonstration.

In the system, the blue symbols presents mobile network base stations that are supplied by the network. The yellow symbols are base stations that are supplied by a backup battery and the red symbols are base stations that are down. The remote-controlled switches that have a working telecommunications link are presented with bright blue symbols, while the switches that do not have a working telecommunications link are presented with a similar white symbol. The dark gray symbol indicates the switches that have a working telecommunications link even though they should not have any based on the simulation. The yellow lighting symbols on the right side of the picture are lightning strikes.

One of the main results of the case was that the disturbance did not affect the mobile network and switches immediately, because the base stations had backup power (see Figure 4.17a and Figure 4.17b). Another important result was that the results of the modeled situation of the mobile network and the real situation did not match. Based on the modeled situation, the first switches became unreachable two hours earlier than in the real case. Additionally, in the model, the number of the switches was greater than in the real case. The main differences between the modeled data and the real data were on the edges of the observed area. Further, the added historical case functionalities enabled the demonstration to cover network development and preparedness planning presented in the second version of the concept (see Figure 4.5).

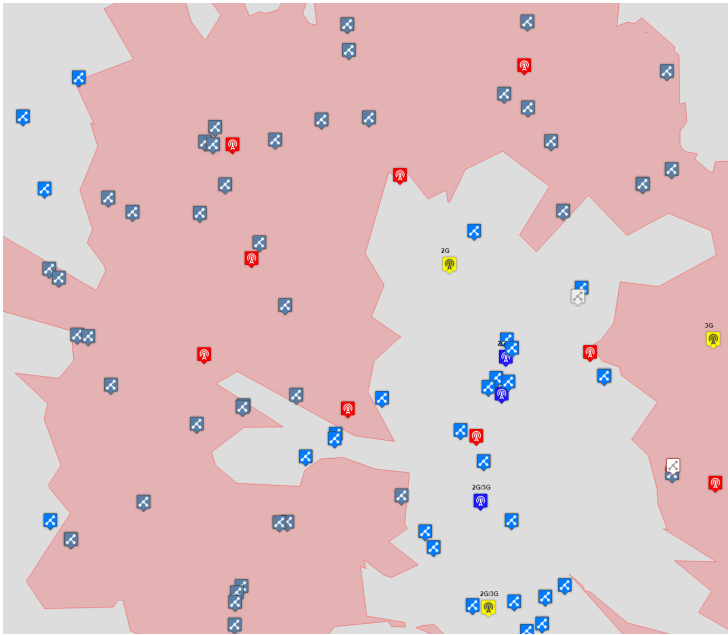
One main problem with the comparison of the measured and modeled data is that the coverage area was generated only from a specific area and did not include the coverages of the surrounding base stations. In a mobile network, the coverages have some overlap. Thus, some of the switches may have got the telecommunication link from outside the observed area. The results of the comparison were most accurate in the middle of the observed area. Thus, the modeled area in this study should have been larger.

Based on the studied case, DSOs can use the historical case functionalities of the SA system to analyze their restoration process. Additionally, it can be used in restoration planning of the electricity and mobile network by detecting the interdependencies between both networks. DSOs and MNOs can use the system to locate the most important base stations for the electricity network. Thus, DSOs can restore the electricity at first to those base stations to ensure the communication of the own remote-controlled devices like switches. Additionally, MNOs can plan the locations of the transferable backup batteries so that the most important base stations for DSOs' communication are ensured. Further, the system can be used to develop both networks. The electricity supply for the most important base stations can be ensured, such as by laying new cable or by improving their backup. Moreover, authorities and municipalities can use the historical part to analyze how their processes worked during a disturbance. If the location of people with safety phones are added to the system, authors can detect the most vulnerable residents.

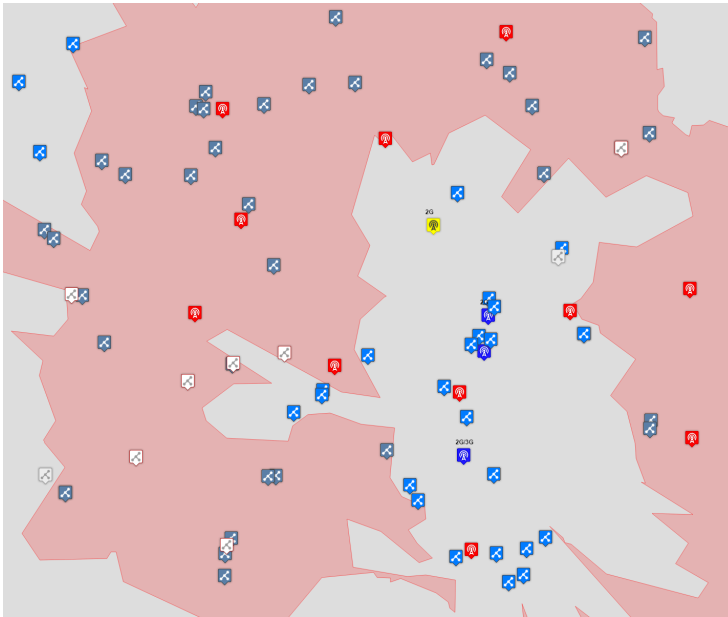
4.5.2 Live demonstration - implementation

The final version of the demonstration of the SAs system combines information about electricity and mobile networks. In addition, it includes layers showing weather forecasts, traffic information and tasks of rescue services. The implementation of the live demonstration was presented in publication VII.

In the implementation process, it was important that the situation awareness system is based on the existing systems and methods used by the DSOs. Thus, the electricity network part employs systems that DSOs already use to inform customers about outages and maintenance. The main information source of the live demonstration is a DMS. It maintains the information about the state of the electricity distribution network. Whenever a change of state occurs in the electricity network, the DMS sends a signal. DSOs use this method to provide information about outages for the customers on the web page. The current state of the network, information when outages started and the approximate ending time of the outages are usually shown on the web page. The same functionality is used for providing an SMS service which informs customers about future maintenances and possible outages. The DMS generates outage information data about the current state of the network when a change of state happens. In addition to the start



(a) Beginning of the disturbance



(b) Worst situation in mobile network.

Figure 4.17: Image of the situation awareness system in different phase of the disturbance.

time and the estimated end time of the outage, the data contains information about the type and description of each outage.

The live demonstration uses the Simple Object Access Protocol (SOAP) or Extensible Markup Language (XML) formatted file to input the data of the outages into the system.

The data is sent over Hypertext Transfer Protocol Secure (HTTPS). If the SOAP is used to send the data, the DMS implements a SOAP client that connects to the SOAP server implemented by the situation awareness system. Whenever a change of state occurs, the changes are added to the demonstration. While the simple file transfer is used, the demonstration polls the server changes on the file.

The outage information is generated at two different levels; a transformer level and a customer level. The information at the transformer level contains the outage information and a list of affected transformers. It is generic and cannot be used to identify any single customer unless the transformer code of the customer is known. The customer level outage information contains more information about the outage, such as the list of affected customer numbers, the certainty of the outage and the state of the outage, such as whether it is a new outage, a recurring outage or if the electricity supply has been temporarily restored. With this data, a single customer can be identified.

The received data is saved into a relational database, such as MySQL (SQL is an abbreviation of Structured Query Language) or PostgreSQL. At first, the data is parsed and combined from different levels (transformer and the customer levels). Each outage has a unique identifier that is used to combine the information.

Users connect to the live demonstration with the web-based user interface. The information in which the user is interested is personalized based on the previously set organizational information and user settings. The received data is further parsed on the user's browser and displayed to the user. The user can filter the data further from the user interface. The user interface keeps on polling the server for changes in the network to keep the information up to date.

Likewise, the electricity network part of the live demonstration, the implementation of the mobile network part of the system is based on an existing infrastructure of a MNO and accurate configuration data available for a certain area in Finland. The individual coverage areas have been accurately simulated with a mobile network simulation tool where all necessary configuration parameters have been considered. The parameters include information about the base station locations, antenna heights, antenna directions, antenna tilting levels, antenna models and their gains, transmission powers, any additional losses and the used frequencies for GSM and Universal Mobile Telecommunications System (UMTS): the second generation (2G) and the 3G cellular networks. Additionally, the environment is considered with different morphographic corrections. The Okumura-Hata (Cichon et al. 1999) path loss model is used to calculate the final coverage areas for each cell. If a problem occurs in the mobile network, the information about it will be sent to the demonstration. Then the corresponding cells are visualized in the user interface. Only lack of coverages are presented in the system.

Information about the base station can be combined with electricity outage information based on the customer identification code or the transformer code. This information can be used to find out whether the base station is not currently supplied electricity from the network. In addition to fault information, the information about the status of the cells is imported to the system to enable the system to visualize the lack of coverage, such as in the maintenance work.

Other information fetched to the demonstration is weather information from the FMI. FMI provides a Web Feature Service (WFS)-compatible interface for weather information. Information about the forecasts, current weather and historical information can be fetched from the system using Hypertext Transfer Protocol (HTTP). Additionally, the Finnish

rescue services provides an interface for media and other users to fetch information about their current activities. Like the weather information, this data is fetched to the demonstration using the HTTP. Further, information about the current traffic situation is fetched from the SOAP-interface provided by Finnish Transport Agency (FTA).

One main part of the demonstration is the database which includes information about sites that are critically dependent on the electricity supply. The criticality data is received from the users. It can be imported to the system using two methods; through web-based user interface, manually adding new sites, or by integrating the stakeholder's own database to the system. The first method is viable in cases with a low number of sites, such as in the case of a small water utility. The second method would be necessary in cases of a high number of critical sites, such as a municipality's clients. If the user's database is integrated with the system, the information about the critical site is updated automatically.

4.5.3 Live demonstration - Case Finland

In the second case study, the demonstration was tested with live operational networks in real time. In addition to researches, representatives of one DSO, one MNO and one field communication service provider were allowed to use the system to provide feedback. The live demonstration case study was presented in publication VII.

The main purpose of the live demonstration was to present how a situation awareness system for disturbances in electricity networks can be implemented and how suitable it is in practice. The demonstration combined real-time information about the outages from four DSOs and one MNO. The studied area was the operation area of those DSOs. The demonstration illustrated the lack of coverage areas in the mobile network and outages of the electricity networks at the transformer level on a map view. Additionally, the base stations that had faults were shown on the map (illustrated in Figure 4.18). Further, the users of the system could add their own critical sites to the system. The sites without electricity were detected based on their transformer number. In this case study, the criticality information was simulated manually to the criticality database, as in previous demonstrations, to avoid the privacy protection issues.

An interface between the mobile networks system and the demonstration was developed to implement the real-time functionality. It was near real-time, because the fault information from the mobile network was collected every 10 minutes from a file generated and sent by MNO. Further, the information was extracted and the possible changes after the previous fault update were visualized. The disturbance data of the electricity networks was collected every five minutes from the web page interfaces of the DSOs.

The demonstration was tested live for two months in this study. No major disturbances did occur during the testing period. However, several small disturbances in the electricity networks occurred. In a few cases, a small electricity network disturbance resulted in an outage in one base station of the mobile network (illustrated in Figure 4.19). However, it did not affect the mobile network coverage, because of the overlap from the nearby base station.

There were some challenges in this case study, as the coverage areas changed depending on multiple variables like transmission power and the weather. The simulated areas do not exactly match the real ones. The edges of the coverage areas, especially, were inaccurate. Thus, some caution must be used in decision-making based on the coverage areas.



Figure 4.18: Disturbance shown on live demonstration.

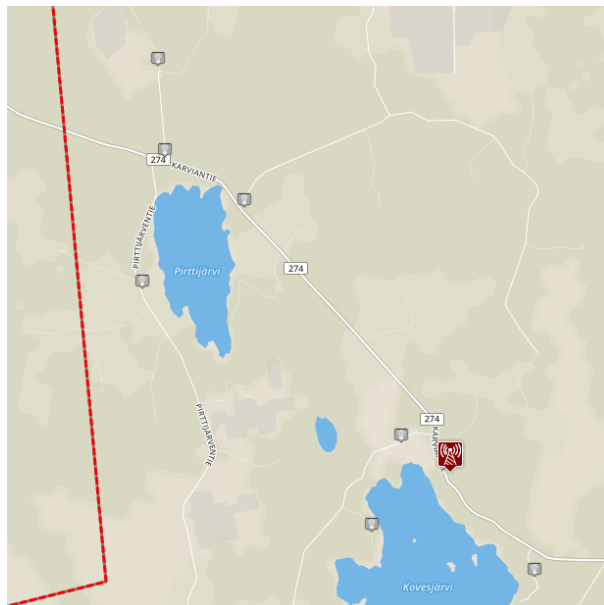


Figure 4.19: Base station without electricity.

The live demonstration improved the information that DSOs receive about the disturbances of mobile network by adding the lack of coverage areas on the system. This can help DSOs to focus their repair process more accurately. One of the main results of the live case study was that it is possible to combine information from multiple electricity and mobile network into the same view. Further, based on the study, additional data, like weather forecasts and fire and rescue services' tasks can be integrated into the same view. With the filtering function the number of the information in same view was kept in an

acceptable level. The main result of the live case was that implementing a situation awareness system for disturbances in electricity networks is possible by integrating the data from existing systems. Although only small disturbances occurred at the testing time, the test users of the system were delighted by the system. They thought that this kind of system would improve their situation awareness during disturbances and reduce the number of information sources.

4.6 Conclusion of situation awareness system

The design process for the demonstration of the SA system can be divided roughly into: a functionality specification, three concepts, three versions of the demonstration and two case studies. In the functionality specification part, the main functionalities of the SA system were recognized. Additionally, it was noticed that existing systems could be used in implementing the SA system. Further, some challenges in the execution of the system were noticed, such as privacy protection issues, the large number of users and how the system would function if there were no electricity supply or telecommunications in the area.

Based on the first concept, the structure and users of the SA system were identified. This concept was a basis for the first version of the demonstration of the SA system. Further, the first demonstration presented the manually-generated electricity network outages, weather forecasts, traffic reports and fire and rescue services' tasks on a map. This version, verified that this information could be integrated on the same system.

The first demonstration was evaluated through a heuristic evaluation (Nielsen 1993). The main result of this evaluation was that the demonstration was easy to use, and users did not need special training to use it. Based on the heuristic evaluation, the demonstration was an improvement over the presently-used DMS service, which employs highly technical material. However, smaller issues in the user interface were recognized. Thus, the concept was improved and the second demonstration was developed.

The second version of the demonstration was harmonized and designed to be clearer than the first one. The results of the first interviews affected the second demonstration, and new functionalities were added, like the filtering function. This version was presented to possible users in interviews and in workshops. It was shown to improve, especially the information exchange between DSOs and municipalities. The results of the interviews and the workshops revealed more information about functionalities were still needed. Thus, the third version of the demonstration was implemented and the concept was developed further.

In the third demonstration, the view was clarified further and new functionalities, like customized information layers, were added. The main change from the previous versions was that coverage areas of mobile network were added. This was one of the main functionalities users wanted. This version of the demonstration showed that the information about electricity network outages and the disruption of mobile networks can be combined into the same view.

To test the third version of the demonstration, two case studies were conducted, a historical data case and a live demonstration. In the historical data case, the demonstration was used to present a real disturbance that happened in Finland. A timeline to follow the whole situation was implemented. Additionally, information about remote-controlled switches were added. Further, information about lightning strikes was added, because it

was requested by the MNO that provided the mobile network data. The historical case showed that the interoperability of the electricity networks and mobile networks can be detected through a combined SA system. Based on this, the SA system could improve the restoration process of both networks.

The live demonstration was implemented to test the system in real-time use. The live demonstration combined information from multiple DSOs by integrating the information from their existing systems. Additionally, most real-time information from the MNO system was integrated into the demonstration. This showed that the combination of data from multiple stakeholders can be implemented using the existing systems.

5 Benefits of the SA system

This chapter describes the benefits of the method using the situation awareness system during disturbances in electricity networks. It bases on results from publications [VII, VIII]. Additionally, the existing SA systems are compared to the presented demonstration of an SA system. The comparison is an updated version of the results from publication [IV].

5.1 Comparison of existing SA systems and the developed system

The developed SA system is compared to present systems used during disturbances in electricity networks in this subsection. Present systems are presented more precisely in section 3.2.5. Results of the comparison are shown in table 5.1, where "*SA system*" means the latest version of the concept and demonstration of the SA system developed in this study. This section updates the results of the comparison described in publication IV. The comparison was made based on published information about the the existing systems. It focuses on the main motivations, technical execution, details and system users. The purpose of the comparison is to find out how the developed SA system would improve the present methods of forming situation awareness during disturbances. Most of the studied systems have been developed for disturbances in electricity networks. However, the MASAS system was developed for all emergency situations. The SA system developed in this study is meant for disturbances in electricity networks. Additionally, it is extended for disturbances in mobile networks and can be extended to cover other critical infrastructures.

One of the main variations between different systems concerned the motivation for developing the system. In Finland, legislation demands that DSOs share information about outages to authorities. Thus, the development process of the KRIVAT, GridWise, Elenia's system and the SA system of this study are based on the legislation requiring that DSOs exchange information between authorities to form situation awareness during disturbances. Additionally, the MASAS background is similar. It was developed by the government. The other systems were developed based on the customer needs.

There is some variation between users of the systems. Those systems that are maintained by DSOs are more restricted to smaller users, such as Elenia's system, which is only used by their control room and contractors. MASAS, in contrast, was developed for all stakeholders during emergencies and for all citizens affected by the emergency. Additionally, KRIVAT was developed for all stakeholders during disturbances in electricity networks.

Table 5.1: Comparison of the SA systems.

		SA system	KRI-VAT	SiRena	PRO-NET SIS	Grid-Wise	Elenia	SUSIE	MASAS
Basic use of the system	Disturbances in electricity networks	x	x	x	x	x	x	x	
	Emergency situations	x		x					x
Motivation	Legislation or Government	x	x			x	x		x
	Other stakeholders' wish	x	x	x	x			x	
Completeness	In use		x		x	x	x		x
	Pilot (in use)			x					
	Demonstration or project	x							
Technical execution	Peer-to-peer				x	x	x		
	Hub-based	x	x	x					x
Communication method	Map	x	x	x	x	x	x	x	x
	Chart	x	x	x	x	x	x	x	x
	Phone call				x				
	SMS	x		x	x	x			
	Email				x			x	
	Video								x
	Possibility to input picture/photo			x		x			x
	Chat		x	x					
Specific database for SA use	Text		x	x		x		x	x
	Criticality information	x							
Administration	Resources						x	x	x
	Commercial/DSO		x		x	x	x	x	
	Government								x
	University	x		x					
Users	Authorities(e.g., fire and rescue services, police)	x	x	x	x	x			x
	DSO	x	x	x	x	x	x	x	x
	MNO	x	x						x
	Emergency management			x					x
	Rescue/emergency response center				x			x	x
	Government			x				x	x
	Municipalities	x			x			x	x
	Voluntary services	x							x
	Citizens	x		x					x
	Other companies				x	x	x	x	x
Media		x			x		x	x	

One of the main differences in the developed SA system, is that it combines information from multiple DSOs. Only KRIVAT does the same thing. This functionality reduces the number of systems needed during disturbances and improves the overall situation awareness. Another main difference of the developed SA system is that it provides more accurate information about the state of the mobile network than existing systems.

The main improvement of the developed demonstration compared to others is a criticality database. It is the only system that gathers the information about sites that are highly dependent on electricity, like special health care patients; moreover, it is the only system that processes this information further. Other systems primarily have databases for available resources. The main weakness of the demonstration of this study, is that it has not been implemented in real use.

5.2 Benefits of the situation awareness system

The demonstrated SA system offers further processed information for stakeholders during disturbances. One of the main purpose of the system is to reduce the number of information sources. With this system, the disturbances in electricity and mobile networks can be observed simultaneously. The information of the interoperability of the networks improves the restoration process of the both networks. Further, the combined information can be used by all stakeholders. The benefits of the SA system can be classified based on how the system is used, whether it is used for planning and training purpose or for live monitoring of the situation.

The criticality database allows the system to offer level-three situation awareness (Endsley 1995) by presenting information about consequences (presented in Table 5.2). With this information, authorities can detect critical sites that need help because they do not have electricity or mobile service. Benefits of the live SA system are analyzed based on the main stakeholders of the major disturbances in the following subsections.

5.2.1 Benefits for DSO

The main benefits of the SA system for DSOs are listed in Table 5.3. As seen in the historical case and in the live case study, the SA system can be used to plan the repair order of the electricity network so that the interdependencies of both the electricity and mobile networks are considered. In that case, the repair order can be changed so that the most important base stations of the mobile network used by the remote-controlled devices of the DSOs, are restored first. Additionally, the most disturbance-vulnerable electricity consumer sites can be considered in the fault repair order. This helps DSOs to plan their restoration process more effectively. Further, the SA system can help DSOs and MNOs to improve their network planning by recognizing existing problematic areas.

Table 5.2: Levels of SA, that developed SA system offers.

SA Level	Information offered by developed SA system
Level 1	Outages of electricity networks Location of important base stations of mobile networks Location of repair teams Current weather data Locations of remote-controlled devices are known Information about tasks that rescue services have Traffic information Information about location of their own critical sites, (e.g., water pumping stations). Information about the location of customers whose lives are dependent on electricity
Level 2	Information that there is a disturbance situation in electricity network Information that there is a disturbance situation in mobile network Information filter (e.g. municipality lines) History data of previously happened disturbances
Level 3	Warning when the critical time of critical site or customer is going to exceed Areas that do not have mobile network coverage Information that repair team does not have mobile network connection Weather forecasts on a map

Table 5.3: Situation awareness system benefits for DSOs.

Present situation	With SA system	Benefits of the system
Customers with high consumption of electricity are known.	Customers who are heavily dependent on electricity are known.	DSOs can consider these sites while planning the network or planning the restoration order.
Location of none or some important base stations of mobile networks are known.	Location of all faults in base stations of mobile networks are known.	Base stations most important to DSOs' operations can be detected and secured.
There is an inaccurate awareness of mobile network coverage.	There is a detailed awareness of mobile network coverage.	DSOs can predict the possible disturbances in their own network caused by the mobile network.
Locations of repair teams are known.	Information is available if the repair team does not have mobile network service.	Repair team can be informed beforehand where to proceed when they need to find some coverage.
Locations of remote-controlled devices are known.	Warning is received if remote-controlled device does not have mobile network coverage.	DSO can predict if this affects their restoration process.
The data of the outages is stored. However, it is visualized manually.	Historical functionalities can be used to visualize the disturbance situation afterwards.	DSO can analyze and improve the restoration process.

Based on the historical case, one benefit of the system is that the DSO and the mobile

network operator can find out how their recovery process went. They can detect if everything went as planned. If it did not, they can determine if the problems were caused by someone other than their network.

Based on the studied cases, the mobile network base stations can determine, which batteries are working less time than they should be. The DSO can use this information to plan their restoration process so that the electricity will be restored first to those locations. In addition, the mobile network operator can use this information to find out if some of their batteries are not working like they should. Further, if the locations of mobile network important base stations are known, the DSO can make those areas more resilient (e.g., by laying ground cable, or by changing the communications media of their remote-controlled equipment in those areas).

The information about the lack of mobile network coverage can be used to inform the repair teams and the contractors about possible communication problems (e.g., a repair team can be warned if they are approaching an area with no mobile connection). Knowing which base stations are currently active and where the mobile network coverage is, the teams can navigate to the correct location to communicate with the control room. The same coverage information can be used to observe whether the remote-controlled switches are in the area. Based on this information, DSOs can predict if the connection between the remote-controlled switches and the control room will be lost.

In extreme weather conditions like storms, the information about the disturbances in the neighbor a DSOs can help DSO to predict future outages in its own network. If the weather forecast is added to this information, the SA system improves the contingency plans for problems within its own network.

One benefit of the system for DSOs is a decreased number of views in the control room. At the moment, control rooms have multiple views, showing different information, such as one for the weather forecast, another for mobile network disruptions. The SA system combines most of these information sources into one view to decrease the workload.

Furthermore, DSOs can use the SA system to fulfill the requirements of the legislation. For example, the Finnish Electricity Market Act requires DSOs to supply any relevant information about outages to the responsible authorities to form a situation awareness.

5.2.2 Benefits for MNO

The main benefits of the SA system for MNOs are listed in Table 5.4. The SA system can increase the situation awareness of the MNOs by combining the information about the electricity network and the base stations of the mobile network into one view. The MNO can use the information about the disturbance in the electricity networks, to predict the possibility of a disruption in its own network.

Table 5.4: Situation awareness system benefits for MNOs.

Present situation	With SA system	Benefits of the system
There is inaccurate information about the running time of the backup power of the base stations.	Receive a prediction of how long the mobile network will operate with backup power after the first outage.	MNO can use this information to replace poorly functioning batteries.
Location of the most important base stations for mobile network coverage is known.	Location of the base stations that would be most important to the restoration of the electricity network is known.	MNOs can improve their backup for the most important base stations to expedite the coverage restoration process of the mobile networks.
There is no information about critical customers that are highly dependent on mobile coverage, (e.g., home-care patients, retirement homes).	There is information about which base stations are most important to the critical customers, (e.g., retirement homes).	Critical sites can be considered when installing the backup power of the base stations or in network planning.
Receive warning if base station does not have electricity supply from the electricity network.	Receive estimation of the end time of the outage.	MNOs can predict if more backup power is needed for base stations.
There is an inaccurate awareness of disturbances in electricity networks.	There is detailed awareness of disturbances in electricity networks.	MNOs can predict the possibility of disturbance situations in their own network.

MNOs can use the live information to predict the number and the location of portable backup power needed for the base stations. This will improve the planning of backup power more precisely and decrease situations where multiple stakeholders bring portable backup power to same site (e.g., if base station is used both by the MNO and the state security networks). Additionally, the base stations that are the most important to the resilience of the electricity network can be secured with longer-lasting batteries. This can improve the restoration process of the mobile networks.

Further, the MNOs can use the information about the disturbance areas to determine the most vulnerable base stations in their own network. The information can be used to cooperate with DSOs in the network planning process. They can detect the most vulnerable areas for the operations of both networks and secure the functions by planning the backup power together. Additionally, the information can be used to plan the restoration process together so that the electricity will be restored first for the most interdependent locations.

One main benefit of the SA system for MNOs is that they detect backup batteries that are not working as they should. This information can be used to replace the poorly functioning batteries.

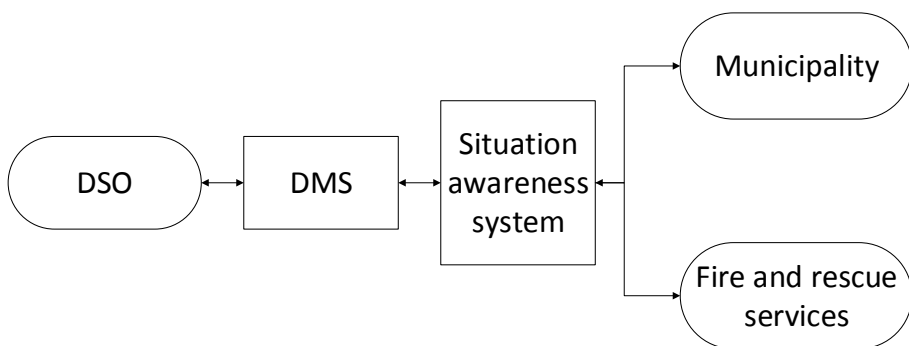
5.2.3 Benefits for authorities and municipalities

The main benefits of the system for authorities and municipalities are listed in Table 5.5. The SA system offers the information about the disturbances in electricity and mobile networks in one view. The fire and rescue services can use that information to prepare an increasing number of tasks and summon officers to duty.

Table 5.5: Situation awareness system benefits for Authorities and Municipalities.

Present situation	With SA system	Benefits of the system
There is inaccurate information about disturbances in electricity.	Detailed locations of disturbances in electricity networks from multiple DSOs is presented in one view.	Authorities and municipalities can improve the planning of their own processes.
Information about location of their own critical sites, (e.g., water pumping stations is known).	Warning if critical site does not have electricity supply or mobile network coverage is received.	Municipalities can plan which sites need backup and which can be substituted, (e.g., do they bring backup power for a water pumping station or ration water among residents).
There is inaccurate information about mobile network coverage.	Detailed awareness of mobile network coverage is presented in one view.	Authorities and municipalities can improve the planning of their own processes.
There is information about the location of customers whose lives are dependent on electricity supply or mobile network coverage.	Warning if critical customer does not have electricity supply or mobile network coverage is received.	Authority or municipality can predict whether residents need to be evacuated or otherwise helped.

The combination of information from multiple DSOs and MNOs decreases the number of information sources and the workload of the authorities. The improved situation for the SA sources is illustrated in Figure 5.1(compare to Figure 3.3).

**Figure 5.1:** Authorities and municipalities improved sources of SA.

Municipalities can use the information about disruptions in mobile networks to follow the situation of citizens with safety phones or emergency buttons. If a customer with a safety phone lives in area of a mobile network outage, the municipality can send help or evacuate the customer. Thus, they can better focus their actions. Overall, the authorities and municipalities can use the SA system to detect critical customers and critical sites. That information can be used to plan an evacuation or to plan the locations of the portable backup power or plan an alternate solution for the site (e.g., share water among residents instead of securing the power supply for a water pumping station).

The SA system improves cooperation during disturbances. The fire and rescue services can help municipalities plan an evacuation together. Further, DSOs can plan the restoration process so that the areas with the critical sites are prioritized. Thus, the resilience of the society during disturbances improves. Additionally, the system can be used for training purposes. While simulating a disturbance to a system, all stakeholders can practice their operations. This can be done as a cooperation, when stakeholders can practice information exchange and sharing roles during larger disturbances or a stakeholder can use the tool to practice their own processes during disturbances.

6 Conclusions

6.1 Summary

Major disturbances in electricity networks are complex situations involving many different stakeholders. The situations are highly stressful and the work load can be overwhelming. Thus, the fluent information exchange between different stakeholders is vital. Based on this study, the information needs of the different stakeholders during major disturbances varies a lot. Thus, there is a need for a personalized tool for achieving the SA.

To improve disturbance management, a method for an SA system was developed. The system combines and processes information about electricity and mobile networks, weather forecasts, traffic information and information about critical customers and sites. The system combines all the information into one view and processes the information further (e.g. lack of the mobile network coverage) to minimize the amount of the information sources for the user. Further, different versions of a demonstration of the SA system were implemented to test the method. One version was tested using a heuristic evaluation and one with interviews; the latest version was tested using two cases; a historical case and a live demonstration. The demonstration used existing systems of the stakeholders.

The present SA systems used during disturbances in electricity networks do not consider the interdependencies between different infrastructures (i.e., the information is rarely processed). Additionally, many of the systems are limited to only a few stakeholders.

In analysis of this study, it was shown that by considering the interdependencies of electricity and mobile networks, the restoration process of both network can be improved. For example, the location of backup power for the base stations of the mobile network can be determined based on which base station is the most important to the electricity network. Additionally, the restoration process can be improved using the information from the SA system for network planning, (e.g., DSOs can plan ground cabling to those base stations that are most important). This will make the restoration process more effective.

The main difference between the presented demonstration of an SA system to present systems is the criticality database. If this information is used in restoration planning of electricity networks, the resilience of the society can be improved during disturbances. Additionally, the information can be used to improve the processes of the authorities and municipalities. With this information they can focus their actions on the right residents, such as safety phone customers.

The main challenge in implementing an SA system is that its based on data produced by customers themselves. Thus, adopting this kind of method depends on the willingness of stakeholders to provide the information. Some of the existing SA systems have had

problems finding customers, because of a lack of variety in the data. Legislation or a regulation which forces the stakeholders to provide data to the system would be the best way to adopt the system. In Finland, the Electricity Market Act requires DSOs to provide the data to authorities, but there is no similar legislation for other stakeholders.

The restoration process of electricity networks has been based mainly on first helping the customers with highest consumption, due to the present legislation and regulations. They guide the restoration process to minimize the number and duration of the disturbances and to minimize the customer outage costs. With the presented SA system, the process can be planned more effectively based on the interdependencies of the critical infrastructures and based on customers and sites which are most vulnerable.

6.2 Discussion and further development

The SA system developed in this study resolves some of the issues in information exchange between stakeholders during disturbances in the electricity supply. Still, there are further development and research needs for the system. Future research should study the performance of the system in real-time. Primarily its impact on the restoration time of the electricity supply. The testing of the live demonstration should continue, especially in cases of major disturbances. To achieve the best results from the testing, the demonstration should be expanded to cover most of the Finnish DSOs and MNOs. The testing should be done with methods related to situation awareness and workload, e.g. Situation Awareness Rating Technique (SART) or NASA Task Load Index (NASA-TLX), to get quantitative results about how the SA system affects the situation awareness or the workload.

This study focused mainly on disturbances in rural areas. The reason for this was that most of the major disturbances in Finland have happened in rural areas. Thus, the experience of those interviewed and participants in the workshops were focused on those situations. However, the consequences of a major disturbance in a city area are different from those in rural areas, because of higher population and city area residents are less prepared for outages. Thus, it should be studied how an SA system could be used during disturbances in city area and whether it improves the disturbance management in that case. Additionally, cyber attacks could be added to that study, because they can be a growing threat to electricity networks.

One main concern in developing the SA system has been that if the disturbance is widespread and there are problems with both electricity supply and mobile networks, how can the functioning of the system be secured? This needs further investigation. One of the existing systems, KRIVAT, has solved the problem, so that when a user purchases the system, they receive a secure communication method for it.

One of the biggest challenges in developing a fully-functioning SA system is the funding of the system and who bears the main responsibility for the administration of the system. If the system is for commercial use, there will be the problem that not all stakeholders are willing to buy it, like in the case of KRIVAT. Additionally, there can be problems to obtaining all the information needed. Some of the stakeholders may not be willing to give all their information and there can be problems with privacy protection, cyber security and system interfaces. If it is own by the government, such as MASAS, these issues may be resolved. However, in that case, there can be difficulties obtaining the money needed and the development process can be slow. One solution could be that it is based on legislation or regulations. This should be further studied.

The existing demonstration should be developed further. New functions that are based on the developed concept, such as automatic warnings for stakeholders, should be added. Additionally, the system can be integrated with other systems used by stakeholders, like with the work management system of the DSOs to follow the locations of the repair teams.

The information that the SA system presents could be processed further; based on the customer number of the base station, it could be determined whether it lacks the electricity feed from the network. If it still working, it means that it is running on batteries. Thus, it can be determined how long the batteries will last. For example, DSOs can predict how long their remote-controlled devices will have a mobile connection during disturbances based on that information. Additionally, MNOs can use the information to plan maintenance of the base stations.

The method presented in this study combines information about electricity and mobile networks and reduces the amount of the information sources of the stakeholders during major disturbances. The SA system improves the restoration process by adding the interoperability of these networks. Additionally, the resilience of the society is improved during disturbances when authorities have information about critical customers or sites lacking electricity or mobile service. Further, this information can be used to prioritize these sites in the restoration process.

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Publications

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DEVELOPING COMMUNICATION BETWEEN ACTORS IN MAJOR DISTURBANCES OF THE ELECTRIC POWER SUPPLY

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ABSTRACT

Storms like Pyry and Janika in Finland in 2001, and Gudrun in Sweden in 2005 raised a thought about the vulnerability of the electricity distribution and the society in major disturbances. In Pyry and Janika some individual customers were left without electricity for almost two weeks. As a result of these storms, actions to increase the reliability of the electricity distribution network were realized. An example of these actions is the standard compensation practice in Finland.

This paper describes organisations, which operate in major disturbances, their present information system applications and their main responsibilities. Also, it clarifies the information that should be provided between the actors. In the project several use cases of this communication between actors were created. Furthermore, a questionnaire was done to almost all Finish distribution system operators in order to understand actors' performance in major disturbances.

In this study came up a result, that there is a demand to more communication between organisations, which operate in major disturbances. This communication can be increased for example by adding information exchange between the information systems of the organisations. Authorities in emergencies have their own communication systems and interfaces. Also DSOs have their own systems to communicate in disturbance in the supply of electricity. However, there is no communication between these systems yet. For the case of major disturbances, an interface between these actors should be developed.

KEY WORDS

Major Disturbance in the Supply of Electric Power, Major Outage, Blackouts,
Communication in Disturbance, Actors in Major Disturbance.

INTRODUCTION

In 2001, there were two storms in Finland Pyry and Janika. Storms involved more than 800 000 customers. There were approximately 90 000 trees fallen on the distribution network. [1]. Some individual customers were almost two weeks without electricity. In Janika thousands of

emergency calls were made to the Emergency Response Centre. Many of these calls concerned trees across the roads and on buildings. Fire and rescue services mostly cleared trees that were fallen. In some areas VIRVE, the Finnish authorities' telecommunication network, did not work for over 2 days. After these storms, the standard compensation practice was developed. It means that customer gets standard compensation if interruption exceeds a certain time. [2].

Actors in major disturbances want more methods to better disturbances management and communication between actors. This research is done in project organized by Tampere University of Technology and VTT Technical Research Centre of Finland. The project studies risk analysis and management methods in major disturbance in the supply of electric power. Several Finnish DSOs (Distribution System Operators), 2 rescue departments, Tekes, National Emergency Supply Agency and Software suppliers are participating to the project.

In this paper, major disturbance in the supply of electric power is defined as a long lasting or widespread interruption in the supply of electric power, during which the fire and rescue services and one or more other public actor (municipality, police, etc.) need, in addition to the distribution network operator, to start implementing measures for reducing possible severe consequences to people and property. This definition does not concentrate just technical aspect, like how much power is missing, it also takes into account consequences that disturbance can cause to customers and society.

This paper presents actors in major disturbances and their information systems. The questionnaire to all finish DSOs has made and some results are introduced in this paper. The questionnaire was concerned question about the need for communication between actors, use cases and challenges in developing this communication. Purpose of this paper is to give understanding to the performance in major disturbance.

ACTORS IN MAJOR DISTURBANCES

Distribution System Operators

Most Finnish DSOs have SCADA (Supervisory Control And Data Acquisition), NIS (Network Information System) and DMS (Distribution Management System). The main function of the SCADA is to collect the status and measurement data from substations and power stations. It delivers the data to the control centre. After that it processes results and displays them to the operator. SCADA enables delivering and implementing status and output of plant to substations and power stations automatically or by the local operator. [3].

NIS consists of the database, the database management system and the applications. Applications use data from the database of the system. These applications are separated from the data. Most important applications for user are the maintenance, design and calculation applications. Common for all NISes is that they have a map based user interface. Information about object's character can be received by pointing it with cursor in the map. Results can be shown on the network map. [4].

DMS connect distribution company's information systems like SCADA, NIS, design applications and customer information system. Common for all the definitions of DMS is the need for a detailed model of network's connectivity and operating diagrams. Entirely integrated DMS connects DSO's processes both vertically and horizontally. Vertical integration contains a real power delivery process and horizontal integration contains corporate IT systems. [5].

Some DSOs has taken VIRVE (Finnish authorities' telecommunications network) to communication use. They use it to communication between fieldworkers and to communicate

with the local rescue department. Many of the Finnish DSOs have an outage web service to customers. The web page gives information about outages places, reasons and durations to customers. Some of services are map based and others are just written text. Map based web pages usually show transformer level outage places and the number of customers in the outage area. [6, 7].

Creating a common operate picture in DSOs can be divided into an internal and external operate picture. The internal picture contains information that DSO need for managing its own processes. It is built by using SCADA and DMS. Those systems are great for internal use because they give information about networks situation. The external operate picture is information that DSOs give to customers, media and other actors. It is made by outage web services and call centres. Some of Finnish DSOs use also SMS-messages to give outage information to customers. *Figure 1* shows flow of the information in DSO. Information between the repairer and the operator is marked as internal in the figure. It is internal if the repairer works in DSO and external if the repairer is working as a contractor. [6, 7].

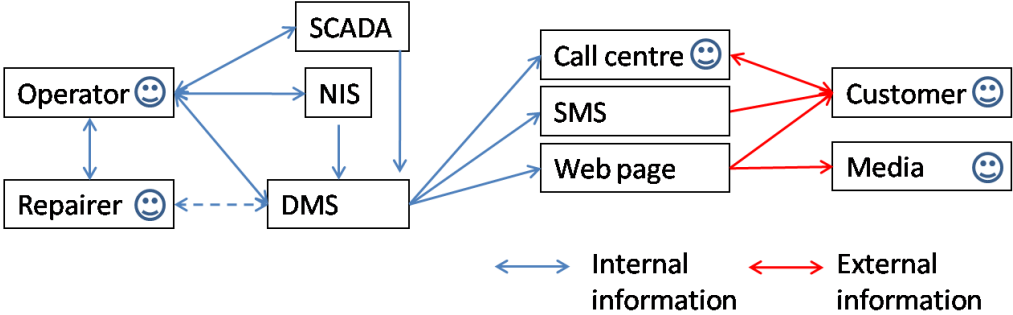


Figure 1 Flow of information in DSO.

Problems related to the internal operate picture are that many times information systems are unattached and that is why creating an overall picture is difficult. Using current systems to common operate picture in major disturbances is also a problem because there are not interfaces to the systems of all important actors like fire and rescue services. [6, 7].

In Sweden, Svenska Kraftnät, Svensk Energi and local DSOs have created information system SUSIE (Samverkan Under Störning Inom Elförsörjningen=Co-operation in Disturbance of Electricity Supply) to help co-operation in major disturbance in the supply of electric power. They have divided Sweden into seven co-operation areas, which all have their own leaders. DSOs can ask co-operation from area leaders when disturbance starts. Leaders get information about situation from maps and weather warnings and then they decide if there is a need for co-operation. They also divide resources for DSOs. DSOs enter information about situation and resources to a systems status report. SUSIE helps DSOs and other actors to communicate during the disturbances. It also helps DSOs to optimize the use of their resources. Municipalities have access to the system. There they can follow the situation. [8].

Emergency Response Centres

In Finland Emergency Response Centres (ERCs) call out fire and rescue, social services and police. ERC operator receives all coming calls. Then the operator evaluates the need for assistance and alerts the appropriate unit or units. The operator advises the caller also on how to proceed. Alert has to be done in 90 seconds after the call is started. At the moment there are 15 local emergency response centres. [9,10]. In major disturbance, the number of emergency calls increase. Many of these calls do not concern a real emergency.

Emergency Response Centres have ELS information system that works in the every centre in Finland. However, the information systems in different ERCs do not share information between each other. Information that Emergency Response Centre gives is an important base to authorities' management and common operate picture systems (COPS). That is why interfaces to other information systems are very important. [11]. System includes the map, where the situation place can be found, and authorities' units can be traced. It includes also a form that operator fills during the call. Authorities are alerted by using the ELS-system. If there is no certainty, about the need of help of some units or authorities, the operator can send notice to warn them. Notices are sent also to hospitals if there is a larger accident. [12]

Emergency Response Centre has started the project to develop their operations and their information systems. The project began in 2008 and it will end in 2015. The aim of this project is to optimize the use of resources. The number of calling centres is decreasing. Information systems are going to be connected so an Emergency Response Centre can receive calls from other centre area if the centre has problems to perform its duty. This situation can come for example in major disturbance if the number of calls increases unexpectedly. [13].

The Rescue Services of the Ministry of the Interior maintain 112info. 112info is used to sending emergency messages to public. The message includes information on the emergency situation from the related authors. In a public web page, everyone has access to the simple messages. There is also a web page for media. That page requires registration. The media page gives more detailed information about emergency assignments. Registered media members get e-mail every time when a new message appears. Most of the messages come from fire and rescue services. Police usually does not send public information about their tasks. [14, 15].

Fire and Rescue Services

There are 22 rescue departments in Finland. Departments have many municipalities in their operation area. Most of the departments have divided their operation area to smaller areas, which have their own fire chiefs. Missions to rescue departments come from the local emergency call centre. Their priority is to protect people, property and environment in danger. [16].

In major disturbance in the supply of electric power, fire and rescue service will continue with their main mission. Disturbance can cause elevators to stop when fire and rescue services are needed to help people who are stuck there. If the major disturbance starts from storm, fire and rescue service could help DSOs to get trees from streets that repairers can go to outage places.

During the research, visits to two rescue departments were made to get to know their role and related actions on major disturbances. Usually communication between DSOs and fire and rescue services is done through Emergency Response Centre. Some rescue departments communicate with DSOs by using VIRVE. Most of the rescue departments have many DSOs in their operation area. They do not always know which DSOs are operating in which area? That will make communication difficult. In Tampere rescue department has made a contract with local DSO. The contract includes communication, for example asking support in major electricity disturbance.

Every rescue department in Finland uses PRONTO, the fire and rescue services resource and accidents statistic system. All accidents and missions are entered to the system. It is used to make the statistics and to manage the resources. The Ministry of the Interior also has access to the system. Other information systems are not common to all rescue departments. Some departments use Merlot and Merlot office management systems. By using Merlot, they can

see the situation of units and operation area. Vehicles have Merlot mobile system. The mobile system helps to get situation right away to map. They can also monitor other units moving from the map. All communication between units and operator is realized by VIRVE.

Police

The mission of the police is to maintain public order and security, prevent and investigate crime and forward investigated cases to a prosecutor for decision. [17] In a major disturbance in the supply of electric power, police's main role is to continue to maintain order and security. Disturbance can for example cause robberies if security systems do not work.

The Finnish Police has made a common communication strategy and defined its development operations for the years 2010 to 2013. The purpose of this strategy is to increase police's visibility and interaction. [18]. Importance of the common operate picture in daily management and planning is increasing to develop the operative action. That common operate picture about the processes of police can be created, communication and information systems have to work well. Interaction between the information systems of the police and Emergency Response Centre is vital for the action of the police, because the most of the missions are given by ERC [19].

Police's communication has to be reliable. It has to happen in right time and to be explicit, realistic and understandable. Communication must be based on common processes, methods and systems that relate on those. By using these, police can create common operate picture. Police's communication strategy suggests create an extranet web service to media in order to develop communication. Media would get notices and other public information through it. [20].

The internal communication bases on the information which is given to personnel in part of daily management. They want to give to personnel possibility to interconnect and to get specialist information. The personnel should always have information at first. In external communication, police want to increase their visibility and give the possibility to communicate with them. [20].

Other actors in major disturbance

One of the main missions of the Finnish Defence Forces is to help other authorities with their duties. One way to help others is to give executive assistance. Executive assistance is used when other authority needs resources or special skills to perform its duties. The Defence Forces help mainly fire and rescue services and police. [21]. In a major disturbance in the supply of electric power, executive assistance could be for example borrowing the defence forces' equipment. Using draftees is more unlikely because there are laws about who can work with the electricity network. If a major disturbance is both widespread and long lasting, like in storm, fire and rescue services may need executive assistance to perform their operations.

Municipalities can be one actor in major disturbance. In major disturbance, there can be for example a need for evacuation. Municipalities are obligated to organize evacuation. In Sweden, municipalities are already part of the power supply co-operation with SUSIE system. [8].

The special health care is an important actor in disturbances if home care patients are taken into account. Life of some home patients is dependent of electricity. In major disturbance special health care would need information if their patients did not have any electricity. In this project these electricity dependent customers are called critical customers. More about critical customers in [22].

Finnish Meteorological Institute (FMI) sends weather warnings to DSOs. Warnings come via e-mail and more exact information is available in a webpage. This information is vital to DSOs in a storm situation. Most important knowledge would be storms forecasts for every hour especially a wind forecast. In future, warnings could come straight to DSO's information system.

Communication between actors

Figure 2 shows the present (blue lines) and the future situation (red lines) of communication in an emergency and in the supply of electricity. At the moment there is some communication between fire and rescue services and DSOs in disturbance in the supply of electric power. Municipalities are not part of the communication in emergencies and disturbances at the moment. FMI gives information to DSOs and fire and rescue services. At present there is no communication between DSOs and critical customers.

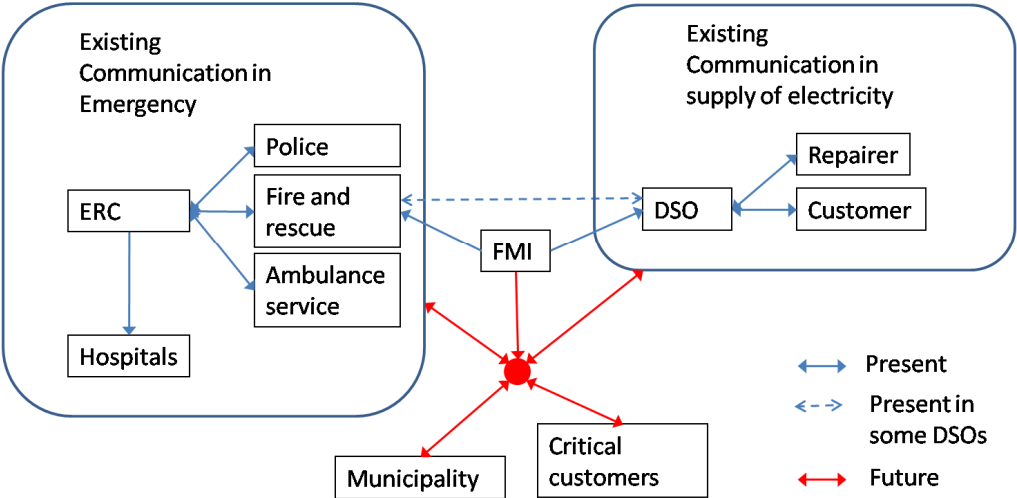


Figure 2 Communication between actors.

In major disturbance in the supply of electric power, communication could come between DSOs and emergency authorities. At the same time, municipalities could be added to communication. FMI's information could be delivered to all actors. Information should be delivered also to critical customers or to the special health care. The number of the actors in major disturbance is large. This cause that number of information will increase lot if communication is increased.

QUESTIONNAIRE

One part of the project was a questionnaire study that was done among the Finnish distribution system operators. The questionnaire was addressed to 86 DSOs. These represented the greater majority of the DSOs in Finland as the total number of DSOs was at the time the questionnaire was done 88. The two DSOs that were excluded from the questionnaire were small DSOs operating in industrial environment and having only a very limited number of industrial customers.

The questionnaire aimed to determine the DSOs' view on major electric power disturbances and had questions under the following topics: 1) The provisional measures taken

by the DSO against long lasting or widespread interruptions in the supply of electric power, 2) DSO's possible experiences related to major disturbances in the supply of electric power, 3) Estimation of the frequency of major disturbances in the supply of electric power, 4) Assessment of the provisional measures taken by the different parties against major disturbances in the supply of electric power (including different type of customers (electricity users) and the different actors of the society that operate, on the basis of the law, in these kind of emergency situations) and 5) Opinions on the need to develop the exchange of the information in respect to major disturbances in the supply of electric power. The questionnaire was realised with Digium Enterprise tool - an Internet-based software service for collecting information and managing feedback.

In total, 51 replies were received including one representing two DSOs within the same energy corporation. Response rate was thus 52 out of 86 that means about 60 per cent.

RESULTS

Present communication in major disturbance

DSOs were asked, which equipment they use to communicate with other actors in long lasting or widespread disturbance. The results of the question are shown in *Table 1*. The most often means of communication was mobile phone. 96.0 % of DSOs used it to communication. After that came landline phone (58.8 %) and e-mail (54.9 %). The VIRVE network is used in 33.3 % of DSOs. Two of the DSOs said, that they also use satellite phone.

Table 1 Means of communication with other actors in long lasting or widespread disturbance

Equipment	N	%
Phone	30	58,82%
Mobile phone	49	96,08%
VIRVE	17	33,33%
E-mail	28	54,90%
Internet (web page...)	13	25,49%
Something else, what?	7	13,73%

Need for more communication

One of the questions was related to the possible need for communication between DSOs and their customers and other actors in major disturbances. Respondents were asked to rate four hypotheses with numbers from 1 (totally disagree) to 5 (totally agree). The hypotheses are presented in the *Figure 3*. Averages in all hypotheses were placed between 3 and 5. The most needed action was H1 (4.06).

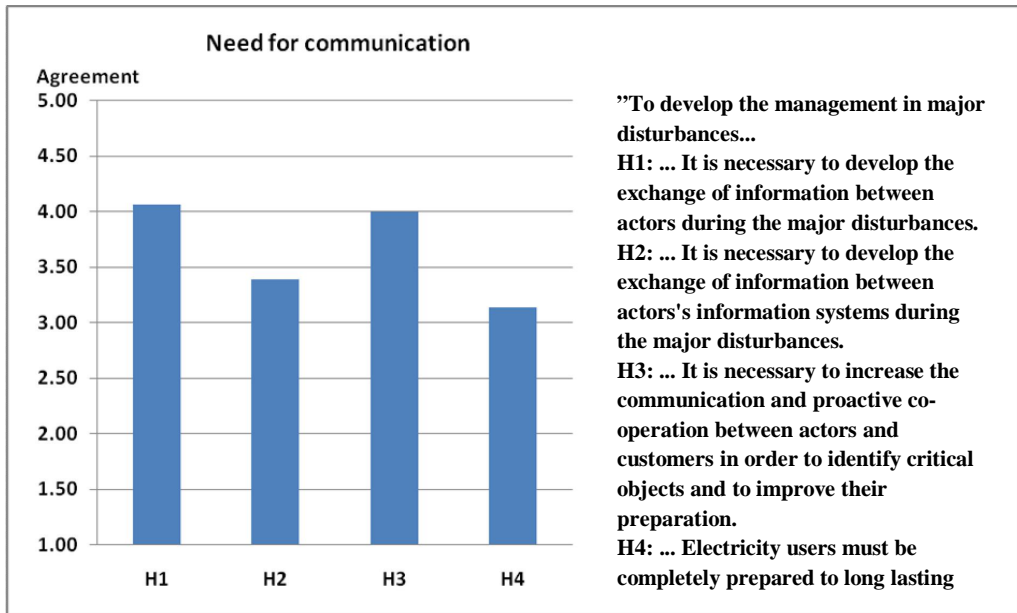


Figure 3 The need for communication.

Use cases

There were presented in the questionnaire several use cases on the information that should move between actors and respondents were asked to rate their significance. There are five examples of these use cases in Figure 4. Respondents rated use cases with numbers from 1 (not at all important) to 5 (highly important). All of these cases were rated between 3 and 5 an average. C3 and C2 were the most significant cases at rates 4.57 and 4.55. C5 was in the last place of these cases at rate 3.32.

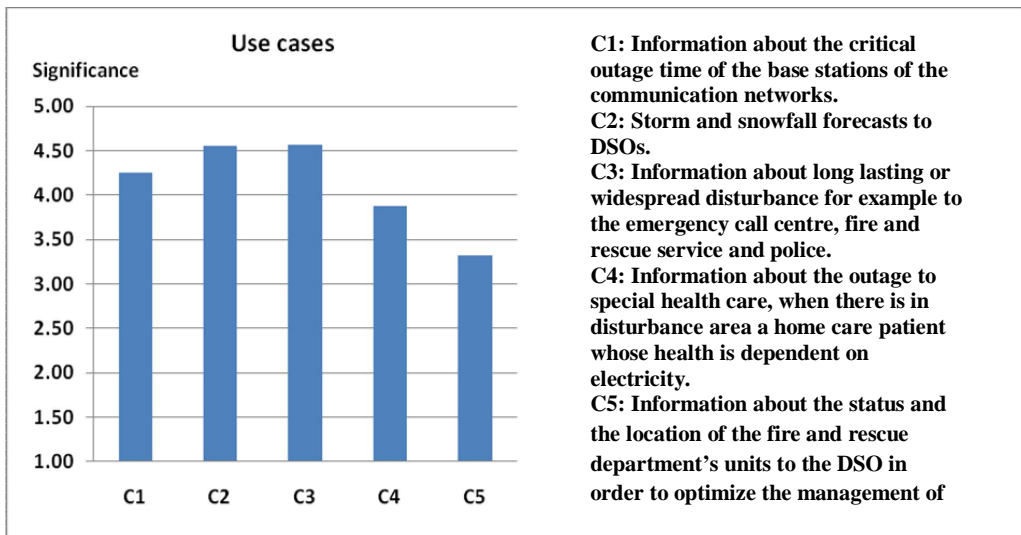


Figure 4 Use cases of the communication between actors.

Challenges

In the questionnaire there was also a question about the challenges in developing the exchange of information between actors' information systems. Suggested challenges are shown in *Figure 5*. Challenges were rated with numbers from 1 (very little challenge) to 5 (very big challenge). The most significant of the challenges were CH7 (4.04) and CH6 (3.98). Least significant were CH2 and CH5.

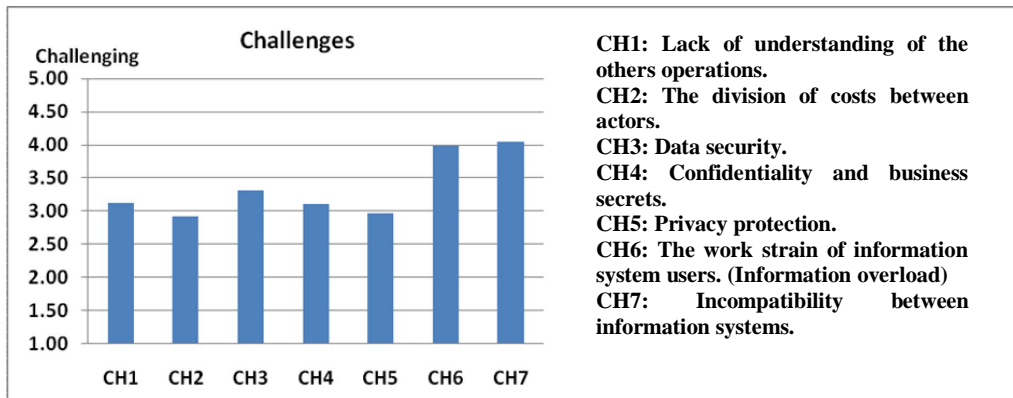


Figure 5 Challenges in developing the communication.

CONCLUSIONS

Fire and rescue service is the most common partner with DSO in major disturbances. That is why it is required in our definition to major disturbances. Emergency Response Centre is also connected to most of the cases, because they deliver missions to authorities. The Finnish Defence Forces can have a major role in disturbance through the executive assistance. They have lots of special equipment and skills to act in disturbance situations for example after storm.

The information systems of the Emergency Response Centre are good examples of systems that can be used to connect many authorities. In major disturbance in the supply of electric power, communication also between DSOs and authorities is needed. Present systems do not support it. DSOs way to contact other actors with using a mobile phone and landline phone can be insufficient. In Janika, the mobile phone network did not work all the time. A phone call does either not include enough information. Satellite phones which some of DSOs use works better in disturbance situations because it is not dependent on the mobile phone network.

The result of our questionnaire was that DSOs want developing communication between actors in major disturbance. Developing communication between information systems was less needed, but is still considerable. A result from use cases was that information about long lasting or widespread disturbance should deliver to other actors. It confirms that more information should move between actors. Other data, which should come to DSOs, was storm and snow forecasts. At present this information does not come straight to information systems. That respondents come from DSOs may have influenced the results of the questionnaire, especially to the use case answers. The same questions should be asked also to the other actors to get more precise results.

Further, this communication between actors should be developed. Developing common operational picture system would be one way to better communication. The system should help actors to get information about situation and others actions. The system could work in between actors' present systems as an interface.

DSOs think that incompatibility between information systems will be challenge if developing communication between systems is started. They are also concerned that there would be too much work strain to operators. The actors in major disturbance come from many different organisations and they all have different information systems. Just only DSOs have several different information systems and they have a problem with unattached systems. Compatibility with other actors systems can be a problem then. If there comes more systems interacting with presents systems, it will also increase work strain. The new system should be integrated into present systems, that user interfaces would be the same in all systems.

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Publication II

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Demonstration of Communication Application for Major Disturbances in the Supply of Electric Power

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SUMMARY

This paper is part of a project that studies risk analysis and management methods for major disturbances in the supply of electric power. In this project, a major disturbance in the supply of electric power is defined as *a long lasting or widespread interruption in the supply of electric power, during which the fire and rescue services and one or more other public actor (municipality, police, etc.) need, in addition to the distribution system operator (DSO), to start implementing measures for reducing possible severe consequences to people and property.* In Finland, in 2001 storms Pyry and Janika and four storms of the summer 2010 are good examples of major disturbances. In these storms, some individual customers were left without electricity even for weeks. Major outage in UCTE's area in November 2006 concerned a wide area in Europe and caused societal consequences even if it was short lasting. As represented in the definition, major disturbances also require actions from authorities. In many previous studies, it has come up that there is a need for better communication between actors in major disturbances.

The main institutional actors in Finland in major disturbances are DSOs, fire and rescue services, emergency response centres, police and municipalities. All the authorities are obligated to maintain their capability to carry out their duties related to major disturbance in the supply of electric power. To improve the existing communication, information about forecasted duration and area of the disturbance is needed. Several use cases of communication between actors have been created in the workshops of the project. The importance of these use cases was asked in the questionnaire for Finnish DSOs. Based on the use cases a concept of the communication application was developed. Users of the system have been categorized into different levels according to their type of action. Based on the concept, a web based demonstration is developed.

KEYWORDS

Major Disturbance, Communication in Disturbance, Web Service, Common operational picture, Disturbance management

1. INTRODUCTION

Need to develop the communication between actors in major disturbances in the supply of electric power have been found in previous studies. Actors involved in the management of major disturbances need improved means to manage the situations and to communicate with other actors. Storms like Pyry and Janika in Finland in 2001, and Gudrun in Sweden in 2005 and Asta, Veera, Lahja and Sylvi in 2010 in Finland caused widespread and long lasting disturbances. In those storms, some individual customers were left without electricity for a few weeks. The major outage in UCTE's area in November 2006 concerned a wide area in Europe and caused societal consequences even if it was short lasting. [1],[2],[3],[4] In January 2011 snow accumulated on trees caused widespread disturbances in Finland. That led to a situation during which a few municipalities arranged voluntary evacuation to some of their inhabitants because of the coldness.

This paper has been made in the project that studies risk analysis and management methods in major disturbance in the supply of electric power. In this paper, major disturbance in the supply of electric power is defined as *a long lasting or widespread interruption in the supply of electric power, during which the fire and rescue services and one or more other public actor (municipality, police, etc.) need, in addition to the distribution system operator (DSO), to start implementing measures for reducing possible severe consequences to people and property.*

In the beginning of the paper, a brief description about the involved institutional actors and their communication in major disturbances is given. In connection to this also the results of a questionnaire directed to Finish DSOs in respect to "the use cases" are presented. Next a concept of the communication between actors that is based on the use cases will be represented. The end of the paper introduces the demonstration of this concept.

2. USE CASES OF COMMUNICATION IN MAJOR DISTURBANCES

The challenges of the communication in emergency situations are the reliability and the security of the information. Emergency management requires rapid information and fast decision making. The accuracy, reliability and timeliness of information have an effect on the decisions. The huge amount of the information is one of the main challenges in communication in emergencies. [5], [6], [7] A major storm is an example of electric power disturbance situation where the communication between several different actors is needed. Getting the information should not depend on the information systems that are used. [8]

The information systems of the Finnish Emergency Response Centre (ERC) can be used as a good example of systems which can be used to connect many authorities like fire and rescue services and police. ERC is also connected in most cases with major disturbances as it delivers missions to authorities. Fire and rescue services are the most common partner to DSOs in major disturbances because their priority is to protect people, environment and property. Other actors can be police, municipalities, the Finnish Meteorological Institute (FMI). [10]

At present DSOs communicate with other actors mainly by mobile phones or landline phones. That can be insufficient because for example in storms mobile phone networks may not work all the time. Some DSOs also use satellite phones which are not disturbed because of storm. However, it is not always possible to provide enough information by phone. These present means of communication do not support effective enough exchange of information between the actors in major disturbances. The present communication is one-to-one and does not give general view of the situation. [10]

The importance of the created use cases was asked from the Finnish DSOs with the help of a questionnaire [9]. It was addressed to 86 DSOs. The response rate was 52 out of 86 corresponding about 60 per cent. One question of the questionnaire represented several use cases on the information that should move between actors. The respondents were asked to rate the importance of the use cases. Importance was rated with numbers from 1 (not at all important) to 5 (highly important). The use cases are presented in Table I with the results of their importance. C6 was the most important. C4 was the second most important case and C11 was in the last place of these cases.

Table I. Use cases and averages of their importances

	Use case:	Average	Median
C1	Information to DSO about the critical outage time of the base stations of the communication networks	4.25	5.00
C2	Information about the reserve power of the customer to DSO	3.47	4.00
C3	Information about critically electric power dependend events (e.g. festival, sports event) to DSO	3.49	4.00
C4	Storm and snowfall forecasts to DSO.	4.55	5.00
C5	Water level information to DSO when flood risk is remarkable	3.76	4.00
C6	Information about long lasting or widespread disturbance to the emergency call centre, fire and rescue service, police et cetera.	4.57	5.00
C7	Information about widespread or probably longlasting disturbance to customer	3.59	4.00
C8	Forecast information about duration of the outage to fire and rescue service and municipalities to support decision making about evacuation	4.08	4.00
C9	Information to authority of special health care, if an electricity dependent home care patient experiences an outage.	3.88	4.00
C10	Information about the status and the location of the fire and rescue department's units to the DSO in order to optimize the disturbance management	3.32	3.50
C11	Information to DSO about areas that arrange a manual water supply	3.20	3.00
C12	Information to DSO about locations where the evacuation is planned or carried out	3.71	4.00

The DSOs wish that information about long lasting or widespread disturbance should be delivered between the actors. Especially information about long lasting or wide spread outages should be delivered to public authorities. Other data, which DSOs want, are storm and snow forecasts. At present this information is not received straight to information systems. All use cases had the support of the DSOs as the use case with the least important got the average of 3.20.

The challenges in developing the exchange of information between actors' information systems were also asked in the questionnaire. DSOs think that incompatibility between information systems will be challenge in developing the communication between systems. They are also concerned that there would be too much work strain to operators. The privacy protection and the division of costs between actors were concerned as less challenging. [10]

3. CONCEPT OF THE COMMUNICATION APPLICATION

A concept of the communication between actors in major disturbances has been created. The concept is based on the results of the questionnaire concerning the use cases and solves most of the cases that were ranked with high importance. The basic idea of the system is that it works an extension to present systems that some Finnish DSOs have. The system combines information about disturbance in the supply of electric power from DSO's information systems and information from other actors. The system may help the actors to receive specific information that they need to when trying to carry out their actions as effectively as possible.

At present some Finnish DSOs offer subscription based outage information services to their customers. In these systems the outage information comes from the distribution management system (DMS). The system sends SMS messages to customers about faults. The messages tell when the interruption has started, gives status information and inform when the interruption ends. [11] Many Finnish DSOs have also map-based web services to present information about outages to general public. The developed concept extends the amount of outage information that systems share by adding the criticality information. At the moment, the communication consists of one-to-one information exchange between electricity user and DSO and a public map. However, the developed concept provides more specific information about criticality and extends the communication to the public authors. It solves the challenges with incompatibility that concerned DSOs, while it is an extension to present systems and does not need new systems.

The concept of the communication consists of a common server that is used by a web service. Information can be sent from the user to server which gives back an operational picture of the disturbance. The information about outages is the main information of the system. Users can store their criticality information to the system. The output from the system is selected by user levels. The

DSO and the public authorities can receive the user's criticality information. The telecommunication operator may want to have information about the location and duration of the outages so that they can estimate the effects of power outages to their system. The concept completes the communication needs that released in the use case part of the questionnaire.

The concept, presented in Figure 1, has been divided into two different parts. The first part is for the communication between different actors. The other part includes information that supports DSO to manage the disturbance. Users are divided into three different levels based on their type of action. This paper concentrates in the communication part of the concept.

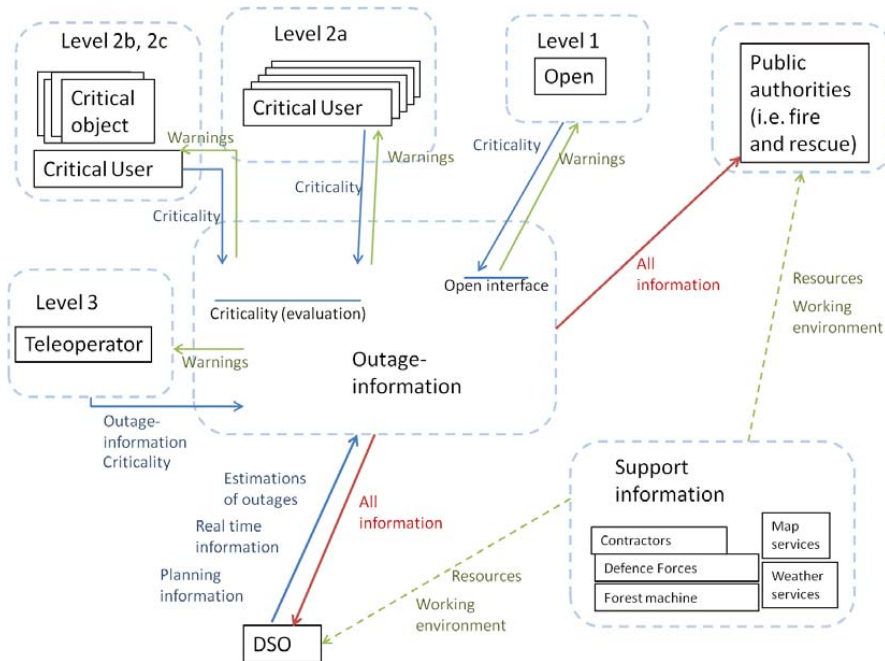


Figure 1 Communication between actors

The first level users consist of general public. They are basic customers like households. These users can inform their criticality to the system and get information about the outages. They use an open interface where information is not supplied to any other user. The user can order warnings about outages related to his criticality. The warnings can be sent via e-mail or SMS. The user can decide when he wants the warnings for example if he wants warnings only in daytime or in certain time of year.

All other users except households are able get access to the levels 2a to 2c. To harmonize the information authorization process is needed. The authorization is carried out by the representatives of DSOs, rescue and fire services and municipalities. The second level consists of the inner levels 2a, 2b and 2c. They are divided by the ownership that they have with the targets. Level 2a users are critically dependent on electricity as a hospital or a rest home. They are able to define themselves to as an electricity critical location. This definition will be send to the DSO and the fire and rescue service. Users have to define their operating areas to the system that their criticality can be evaluated. In a disturbance, weather, time of occurrence of an outage and its duration can effect on the users' criticality of electricity. These effects have to be informed to the system by the user. In the authorization process, it can be decided if the information provided by the electricity critical user is acceptable and consistent, when for example compared to information provided by other electricity critical users in the same area. The described criticality evaluation process is a continuous process and DSO's reliability calculations can be attached to it. User has to update its information regularly. They will inform the system if they have plans that effect on the criticality. DSO can inform user if there are plans for the distribution network that would effect on the reliability of the power supply on which the user is used to. The user gets warning if its location is in outage. If the critical time of the user is going

to be exceeded or is already exceeded, the user can get the warning by SMS message. This exceeding of the critical time can be shown to DSO and fire and rescue service with the icon in the map. As an advanced feature can be that during the disturbance, the some of the users can inform the system of the changed situations for example reserve power is moved to the location or if the location is evacuated. The users are themselves responsible that all information is right and updated.

The level 2b users are users that have more than one electricity critical location in the DSO's area of responsibility. An example of a user belonging to this level is a water utility having multiple pumping stations and other similar type of elements. They are selected by the authorization process like the level two users. In level 2b the user will gather his targets and inform these to the system. The outage information and the warnings are sent to the user who will forward them to the responsible persons. Otherwise, this level functions are like at the level 2a. The level 2c reminds the level 2b. However, in the level 2c users do not own the locations. The users are usually public authors like the special health care and its home care patients for instance. Some of the home care patients like the respirator patients have life supporting machines that are dependent on the electricity. They may need help of the special health care if the disturbance is long lasting. Functions at this level are the same as at the level 2b.

The level three users are telecommunication operators. This part the functions are the same as level 2b and 2c. However, in level three users also gives their own outage information to the system. The DSOs and fire and rescue services will get this telecommunication outage information in real time. Outages of the telecommunication and the electricity could be added to the same map. Further development and studies are needed that this feature could be carried out. More information about the compatibility of the systems that DSOs and telecommunication operators use is needed.

DSOs, public authors like fire and rescue services, police, ERC are actors in the system. They get all information from the users on levels two to three. The outage information of the level one users are given in transformer level. They can use all received information to carry out their main responsibilities to manage the major disturbances. DSOs also give information to the system. This information can be for example planning information, real time information on disturbance and estimations of the situation. These users also get information from the support part of the system. This information is meant to support the management of the disturbance. It includes map services in the system and weather services. It also gives information about resources of contractors, forest machines and the defence forces.

4. DEMONSTRATION

A demonstration of the outage information part of the concept has been created. It bases on a web service. This system demonstrates the view that fire and rescue services can see (Figure 2). The system can be used through internet. Customers will define their criticality of electricity to the system. Fire and rescue services can see the location of the user from the map in the internet page. When a disturbance hits, the icon of the transformer and the critical customers appears.

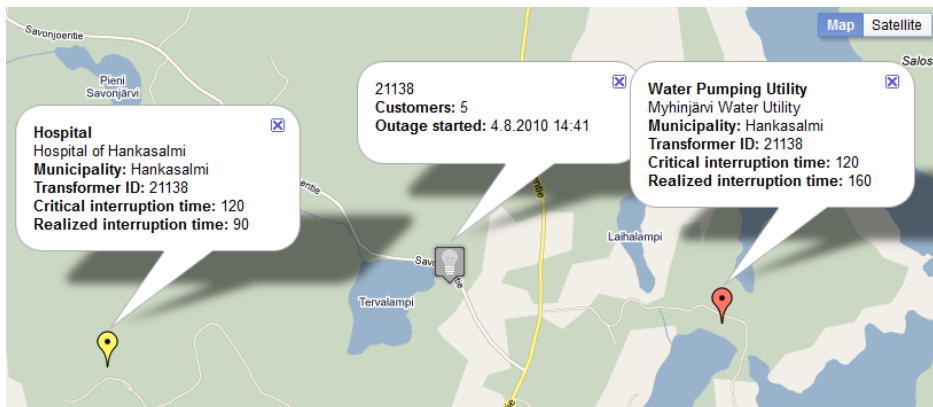


Figure 2. User interface of the demonstration application

The outage is shown by transformer level in the map. In Figure 2, the hospital of Hankasalmi and a water pumping utility are located in outage area. By clicking the icon of user, the text box will appear. The text boxes have information about the user and its critical time. There is also information of the realized interruption time. If the user has an outage but the critical time is not yet exceeded, its icon is marked with yellow. When the critical time has exceeded the icon change its colour to red.

The demonstration can be developed further to more versatile. The icons of users could be changed to show the type of the level of the user. The demonstration could be also extended to show the criticality of the consequences that outage will cause to user. It can be shown by the size of the icon.

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Publication III

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IMPROVING SHARED SITUATION AWARENESS IN DISTURBANCE MANAGEMENT

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ABSTRACT

Many major disturbances in the supply of electric power have taken place in Finland in last decade causing significant problems in the functioning of the modern society. In major disturbances there are multiple organizational actors like fire and rescue services, emergency response centers, police and municipalities along with distribution system operators (DSOs) and network repairers involved in the management of disturbance situations. In previous studies, lack of shared situation awareness in disturbance situations has been noticed. After the latest storms in Finland it is proposed that DSOs should be obligated to co-operate with public authorities and deliver information to them in major disturbances. In this paper, a concept of the shared situation awareness in disturbances has been presented. The paper also presents a demonstration based on the concept.

INTRODUCTION

Storms like Pyry and Janika in Finland in 2001, Gudrun in Sweden in 2005, four storms in the summer of 2010 and storms at Christmas 2011 in Finland caused widespread and long lasting disturbances in the supply of electric power. In those storms, some individual customers were without electricity for a few weeks. In January 2011 snow load on trees caused widespread disturbances in Finland. Typically, these disturbances caused problems in telecommunication, water supply, animals' conditions in farms and with the coldness of houses. The coldness of the houses has led to even some evacuations. In addition to storms that affect the rural area the hurricane Sandy caused widespread disturbance in Eastern parts of the USA in October 2012 including some cities. There were e.g. floods that caused outage to Manhattan in New York. In addition to major disturbances induced by storms and other severe weather conditions there have also been major disturbances that have not been especially long lasting but extremely wide spread, like the disturbances in the transmission systems in the USA and Canada in 2003 and in Central Europe in 2006, which have caused negative societal consequences. [1-7]

In major disturbances there are multiple actors involved, like DSOs, repairers, fire and rescue services, emergency response centres, police, municipalities and customers. All the organizational actors are obligated to maintain their capability to carry out their duties related to major disturbance. Major disturbances cause them also more duties e.g. fire and rescue services help people out from the

elevators and municipalities arrange evacuations. A need to develop the information exchange between actors in major disturbances in the supply of electric power has been found in previous studies [1, 7, 9]. After the latest storms in Finland the Ministry of Employment and the Economy has proposed among other amendments that DSOs should be obligated to co-operate with other DSOs and public authorities and to deliver information to them as well as to their customers in major disturbances. [8]

This paper presents results based on research done by Tampere University of Technology and Technical Research Centre of Finland. DSOs and fire and rescue services participated in the common workshops done in the research. In this research, a major disturbance in the supply of electric power was defined as *a long lasting or widespread interruption in the supply of electric power, during which the fire and rescue services and one or more other public actor (municipality, police, etc.) need, in addition to the distribution system operator (DSO), to start implementing measures for reducing possible severe consequences to people and property.* [1]

In this research a concept of the shared situation awareness in disturbances has been created. The concept will extend the integration of Distribution Management System (DMS) in an unusual direction by taking the other actors into account. In addition to shared situation awareness, it is important that there is a possibility to use the information in network development and when training for disturbance situations. [1] The paper also presents a demonstration based on the concept. Demonstration consists of an internet service which combines information about disturbances in the electric power supply from DSOs' information systems and information from other actors. The demonstration illustrates how the exchange of information between actors could be executed by using a situation awareness system. The system helps actors to receive specific information that they need in carrying out their actions in an effective way.

SITUATION AWARENESS IN GENERAL

Three level model

Situation awareness (SA) is defined as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" in [9]. SA can be modelled as three levels 1) perception, 2) comprehension and 3) projection. The first level is to perceive the status, attributes and dynamics of relevant elements in the environment. Based on this information, the comprehension of the current situation

will be created. The projection about what will happen in the future is achieved through the knowledge of the status and dynamics of the elements and comprehension of the situation. [9, 10]

Shared SA

In major disturbances in the electric power supply, there are always multiple actors. All actors need to get SA from the disturbance in order to plan and carry out their actions effectively. [1] Term “shared situation awareness” comes from military. It is mostly defined as a common view of the battlefield or a common operation picture. In the case of the disturbances, the battlefield could be replaced by the word “disturbance situation”. [11]

MAJOR DISTURBANCES AND SHARED SA

Present

In major disturbances, DSOs form the SA based on the information that they get from DMS, SCADA, weather services etc. Sources of the information are widely spread and the main information comes only from DSOs’ own network. The information that other actors achieve from disturbance comes mainly from DSOs’ public web pages and phone conversations. [1] Decision making and performance in disturbances can be improved by creating systems that enhance actor’s awareness of the situation. [9, 11, 12]

SA Concept

Based on the common workshops, the concept of shared SA in disturbance situations was created. The concept is divided into disturbance management that creates the SA and into risk management that covers the network and preparedness development (Figure 1). This paper focuses on the disturbance management part of the concept.

In addition to the present ways of information exchange in disturbances this concept has a criticality information database, which contains the information of customers who are highly dependent on electricity. DSOs can use this information to network development and in the planning the order of restoring the network in disturbances. Authorities can use criticality information in order to get a picture of the disturbance situation. It helps them to carry out their own actions. The concept is based on the idea that the customer has the main responsibility of maintaining the criticality information.

DEMONSTRATION

The demonstration of the SA system has been developed based on the concept. The users of the system can be divided in different user groups depending on what information they need and based on the privacy issues. The user groups are DSOs, who will enter the information of the disturbance to the system, critical electricity users, who have sites that are critically dependent of electricity, authorities, who will observe critical sites and regular users, who are the customers of DSOs.

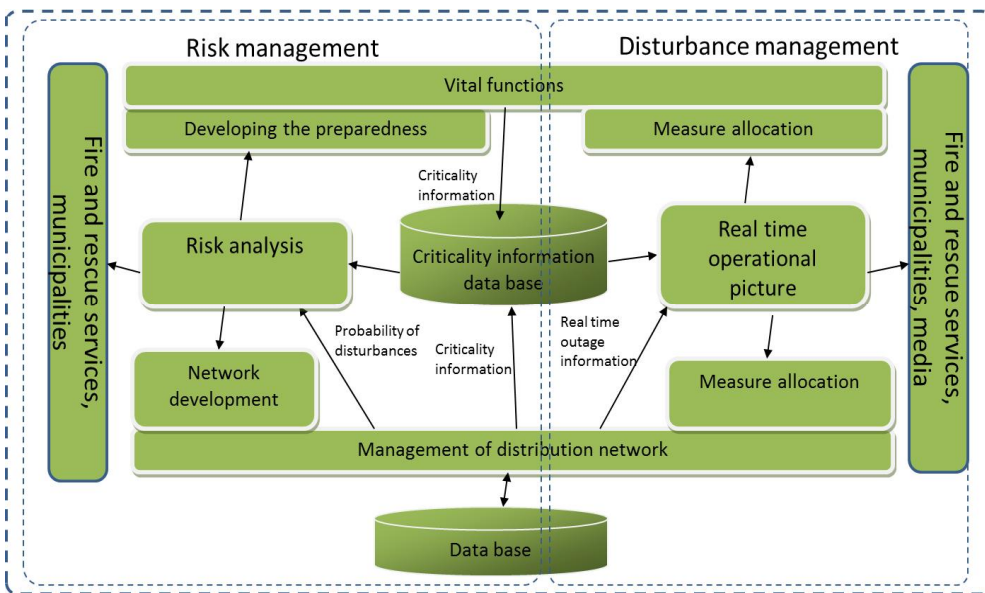


Figure 1 The concept of shared SA

There is a MySQL database that includes information about customers, their sites and dependence on electricity. The information about outages comes to the system as an XML-form (Extensible Markup Language) straight from the DMS. The demonstration uses Google Maps API, which is a programming interface, that enables creating own applications for Google's map service. The Google Maps API uses their own KML (Keyhole Markup Language) which is a file format based on the XML standard used to display geographic data. So the information about outages or any other situation can be brought to the map with XML or KML files (Figure 2).

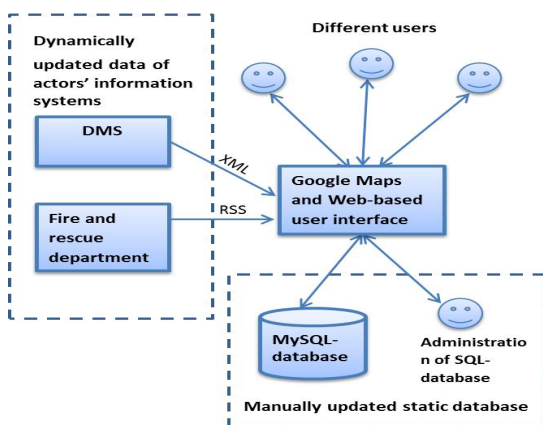


Figure 2 Sketch of the demonstration

The user interface is based on the web page (Figure 3). The user can enter information about his critical sites into the system and manages these later. This information goes to the database. The information about the outages comes from the DMS to the database. A combination of this information is delivered to authorities and DSOs.

In disturbance situation the authorities and DSOs can see all critical sites from the map. The critical electricity users and regular users see only own sites. From the map the users can see where the outages are, how wide spread they are and what are their estimated interruption times. The critical sites are shown in different colours depending on what is the relation of the current interruption time compared with their predefined critical interruption times. System use traffic lights colouring to that. In addition to map there is also the table that shows amounts of secondary substations and number of the customers in outages. The system also shows a list of warnings where user can see information about outage and the critical sites.

CONCLUSIONS

At the moment, the way to form the shared SA in disturbances of the electric power system is working poorly. The shared information comes from multiple sources of different actors, some public web pages, telephone connections etc. If a comprehensive picture on the situation is wanted, several information sources must be used. In a present situation of the shattered SA the management of disturbances is working ineffectively.

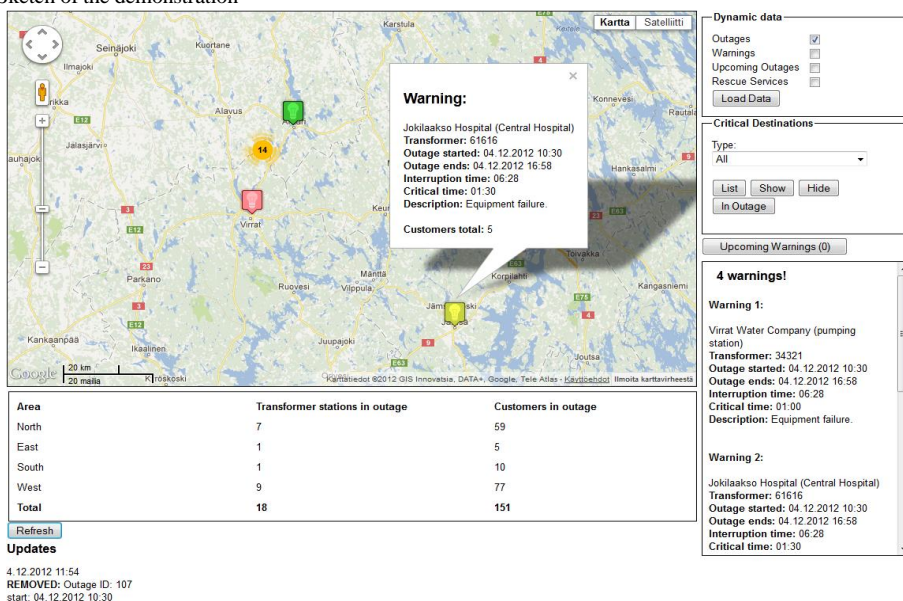


Figure 3 Demonstration of situation awareness system

The way to improve shared SA in disturbance is to create a situation awareness system that would collect all the needed information to the same location. The information that the system shares can be limited to different user groups based on what information they mostly need and based on the privacy issues. Sharing the SA to the different actors is extension to the present way of thinking in the DSOs' information exchange. It will extend the present information sharing with information about the criticality of DSOs' customers to actors. Instead of the present public SA this gives specified view to those who need it.

FURTHER STUDIES

A few DSOs in Finland have started to share information from the DMS into their local fire and rescue services. It is based on the existing systems. It should be further studied how this works in practise. Developing the demonstration presented in the paper will continue by using the incremental software development methods. The participants of the workshops of the research were mainly from DSOs and fire and rescue services. Further, the representatives of the other actors like municipalities should also be interviewed.

The developed concept covers the communication between actors in disturbances and further it can be extended to cover any critical infrastructure. To develop this kind of system effectively, there should be a way to measuring the SA. However, the measuring the SA is uncommon in the field of electric power supply. Further it should be studied what method is the best to measuring the shared SA in the disturbances of power supply. After the right measurement method has been detected it can be used to develop the SA system. Further, comparing between different SA systems has to be done that the most suitable system for disturbance management would be found or developed. The developed system should be tested in a few different cases e.g. with welfare system for the elders.

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Publication IV

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Developing Situation Awareness in Major Disturbances of Electricity Supply

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Abstract—Many major disturbances in the electricity supply have taken place in the last decade causing significant problems in the functioning of the modern society. In major disturbances there are multiple organizational actors like fire and rescue services, emergency response centres, police and municipalities along with distribution system operators (DSOs) and network repairers involved in the management of disturbance situations. In previous studies, lack of inter-organizational situation awareness in disturbance situations has been noticed. After the storms in Finland in 2011 it was proposed that DSOs should be obligated to co-operate with public authorities and deliver information to them in major disturbances. The paper presents a demonstration of the inter-organizational situation awareness system developed in this research and compares it with other systems. The aim of the comparison is to find similarities and differences in the systems so that the situation awareness in major disturbances of the electricity supply could be improved.

Index Terms-- Disturbance management, Information exchange, Power distribution faults, Situation awareness, Web services.

I. INTRODUCTION

Several major disturbances occurred in the past few years. In these disturbances, lack of information exchange between the actors has been noticed. Usually in disturbances, municipalities and authorities receive information by DSOs' web pages, like transformer level maps or lists that show the outages and their duration and phone conversations. This is usually complicated, because there are several different DSOs working in the fire and rescue services operating area or in area of the municipality. [1]-[4]

The Storms like Pyry and Janika in Finland in 2001, Gudrun in Sweden in 2005, four storms in the summer of 2010, storms at Christmas 2011 and two storms in the autumn 2013 in Finland caused widespread and long lasting disturbances in the supply of electric power. In those storms,

some individual customers were without electricity for a few weeks. In January 2011 snow load on trees caused widespread disturbances in Finland. In addition to storms that affect the rural area the hurricane Sandy caused widespread disturbance in Eastern parts of the USA in October 2012 including some cities. There were e.g. floods that caused outage to Manhattan in New York. Many of the major disturbances are induced by storms and other severe weather conditions. However, there have also been major disturbances caused by human mistake that have not been especially long lasting but extremely wide spread. Good examples of these are the disturbances in the transmission systems in the USA and Canada in 2003 and in Central Europe in 2006 which both of these caused negative societal consequences. Typically, the disturbances caused problems in telecommunication, water supply and animals' conditions in farms. Also the coldness of the houses has led to even some evacuations in Finland. [1]-[9]

After the storms in Finland in December 2011, the Finnish Electricity Market act was changed so that major disturbances could be prevented. One addition to legislation was that DSOs should participate in the formation of a situational awareness and supply any information relevant to this purpose to the responsible authorities. [10]

This paper presents results based on research done by Tampere University of Technology and Technical Research Centre of Finland. DSOs, fire and rescue services and one municipality participated in the cooperative workshops done in the research. In this research, a major disturbance in the supply of electricity was defined as *a long lasting or widespread interruption in the supply of electric power, during which the fire and rescue services and one or more other public actor (municipality, police, etc.) need, in addition to the distribution system operator (DSO), to start implementing measures for reducing possible severe consequences to people and property.* [1]

In this research, a concept of the inter-organizational situation awareness in disturbances has been created. The

concept extends the integration of Distribution Management System (DMS) in an unusual direction by taking the other actors into account. Based on the concept a demonstration of situation awareness system has been developed. The paper also compares this concept and demonstration with other concepts and systems which are under development process or are in use.

II. INTER-ORGANIZATIONAL SITUATION AWARENESS IN MAJOR DISTURBANCES

In Endsley's theory about situation awareness (SA), SA can be seen as the triad of "perception", "comprehension" and "projection". In the first level the status, attributes and dynamics of relevant elements in the environment are perceived. At the second level the comprehension of the current situation will be created based on the information of the level one. It is about understanding the meaning of the information. At the third level of SA the projection about what will happen in the future in the situation is formed. In major disturbances, there are always multiple actors who need to get SA from the disturbance in order to plan and carry out their actions effectively. Information, that they need vary depending on their duties. [11],[12]

Usually, the theories of the SA consider mainly organization's internal SA. The basic theory is based on individual's SA and it can be extended on SA of team or shared SA. In shared SA, every individual has their own view of the situation. Same time there is some overlap in awareness between some members or even between every member. The awareness that overlaps is always smaller than individual awareness. In the major disturbances of the electricity supply, each actor needs different information about the same situation. It is similar to the usual case of shared SA. However, in the case of major disturbances there are multiple organizations involved so shared SA has to be extended to inter-organizational SA. [11]-[13]

At present, DSOs' SA is focused on DMS, Supervisory Control and Data Acquisition system (SCADA) and

sometimes on Work Management System (WMS). The main information comes only from DSOs' own network. Usually, DSOs decide the fixing order based on where the customers with high consumption are located and where the faults that cause most trouble with electricity supply occur. In these cases there can be critical infrastructure and customers, whose life is dependent on electricity, in the disturbance area and DSOs do not know that. In addition, the other actors achieve information about disturbances mainly from DSOs' public web pages, like transformer level maps or lists that show the outages and their duration or from phone conversations. Some DSOs' offers Short Message Service (SMS) service, which sends messages about outage's beginning time, estimate duration and ending to the customer. [1]-[4]

III. CONCEPT AND DEMONSTRATION OF SA SYSTEM

The research project to develop the concept of the inter-organizational SA system began in 2008. At that time, there was no similar concept of inter-organizational SA systems for the disturbances of electricity supply. However, some DSOs offered information about outages on their websites. The development process of the concept and demonstration has been iterative and the concept has been extended and developed further after creating the demonstration. This research has also affected other development projects in Finland regarding the SA. Information from the results of these projects has been used to develop the presented concept further.

A. Concept

Based on the cooperative workshops of the research, the concept of the SA system (CIOSAS) in disturbance situations has been created to improve inter-organizational SA. The concept is divided into disturbance management that creates the SA and into risk management that covers the network and preparedness development (Fig. 1). The concept has been developed so that it can be used also in case of other critical infrastructures than electricity supply e.g. water supply. It will carry out the demands on new legislation in Finland.

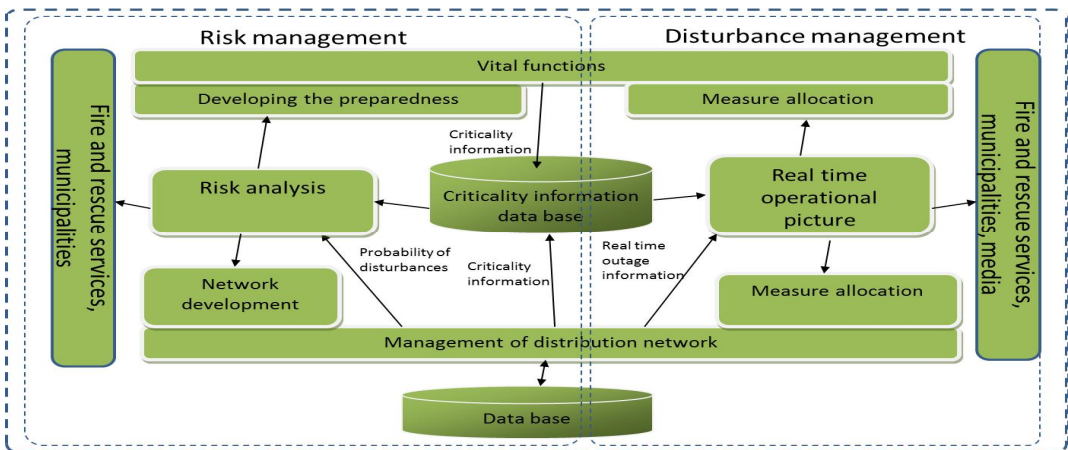


Figure 1. Concept of inter-organizational information exchange

In addition to the present ways of information exchange in disturbances, this concept has a criticality information database, which contains the information of customers who are highly dependent on electricity. The criticality information can be used for planning the order of restoring the network during disturbances and also for network development. Authorities can use criticality information in order to carry out their own actions. Maintaining the criticality information belongs to the customers themselves or to the authority responsible for the customer.

B. Demonstration

The demonstration of the inter-organizational SA system has been developed (Fig. 2) in this project. The demonstration bases on the presented concept. The demonstration consists of an internet service which combines information about outages from DMSs, information from other actors e.g. tasks of fire and rescue services and criticality information of customers.

In the demonstration, all information is gathered to one place and then shared to users. The users have been divided in different user groups depending on what information they need and based on the privacy issues. The user groups are DSOs, critical electricity users, who have sites that are critically dependent of electricity, authorities, who will observe critical sites and other users, who are the regular customers of DSOs. There is a MySQL database that stores information about customers, their sites and dependence on electricity. The information about outages comes to the system as an Extensible Markup Language form (XML) straight from the several DMSs. The demonstration uses Google Maps API, which is a programming interface, that enables creating own applications for Google's map service. The information about outages or any other situation can be brought to the map with XML, KML or RSS format.

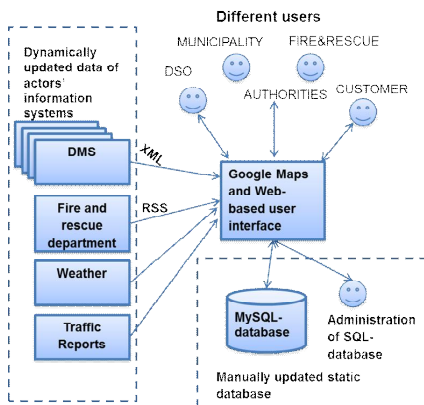


Figure 2. Demonstration of inter-organizational SA system

IV. PRESENT INTER-ORGANIZATIONAL SITUATION AWARENESS SYSTEMS

In the past view years, several concepts and systems have been developed to improve inter-organizational SA in emergencies and in the major disturbances of electricity

supply. Few of these have been presented in this paper. These concepts have been divided based on the countries that they are from, because there are differences in emergency organization structures in every country.

A. Canada

The Canadian Multi-Agency Situational Awareness System (MASAS) has been developed for exchanging emergency management incident relevant information amongst multiple agencies and jurisdictions. MASAS is used as the national SA system for emergency management of Canada. It is not designed specifically for the disturbances of the electricity supply. However, it can be used for sharing information about outages too. The system bases on open source architecture and implementations. The usual way to information exchange in emergencies is a peer-to-peer approach where there are multiple information sources that are connected to each other. However, this method needs multiple changing interfaces. That is why MASAS bases on hub based architecture where the hub helps to decrease the amount of interfaces. The core of MASAS architecture is managed by the Canadian government to ensure that it maintains its focus on interoperability and addresses the needs of the emergency managers it serves nationally. Users of MASAS can be representatives of e.g. municipal, provincial, territorial, federal, emergency management, police, fire and rescue services and infrastructures. [14], [15]

B. Germany

In Germany, there have been two research projects about developing inter-organizational situation awareness in the disturbances of electricity supply. In both projects, the lack of inter-organizational SA in disturbances has been noticed. [16]-[18]

In the Infostrom project, they have been studying inter-organizational information exchange in disturbances of electricity supply in area of two counties. Their aim has been creating "Sicherheitsarena" (SiRena) (security arena in English) which would help different actors to share information. Several problems concerning the inter-organizational information exchange have been found. There are problems with distributed information, missing awareness about available information, policy issues of information, handling the uncertainties of information, terminology issues and perceiving interdependencies between information. They have noticed that main actors in the disturbances of electricity supply are infrastructure suppliers (e.g. power suppliers), public strategic administration (e.g. county administration), public operative administration (e.g. police, fire and rescue services) and citizens. [16], [17]

In Infostrom project, a concept of the inter-organizational SA software has been developed to face these challenges. It is based on a digital map and a resource repository and it allows adding different types of internal and external information e.g. place marks and weather information. Users have opportunity to show and hide information resources from the map and to add additional and new information resources to the map. It has been designed as a web-based solution which is independent of location and platform so in addition to using

the system in office, the actors are able to use it from various places via mobile phones and home computers. For the actor to be aware of available and suitable resources there is information repository where services can be registered, described and rated by users. [17]

Another project in Germany has been executed by the DSO MITNETZ STROM. It has been noticed that there is a lack of communication with local governments, police stations, fire and rescue services and rescue coordination centres e.g. in the past they received information about planned outages only from a daily newspaper. These actors wanted information about the outage and the ongoing restoration process earlier and more precise. That is why a new concept of inter-organizational communication has been developed. Their aim was to develop transparent, target group specific and contemporary communication process. Rescue coordination centres and municipalities were chosen for main target groups. [18]

Based on the concept the system called "PRONET SIS" has been developed. The system filters the needed information about planned and unplanned outages from the grid control system. Then the system sends relevant information to rescue coordination centres by email. The information from the email can be integrated straight to their system. It contains information about the outage, location, and geographical data of the substation, internal information about the affected power stations, the number of interrupted customers and a link to Google maps. A new email is sent every time when there are some changes to the event. [18]

The municipalities wanted more specific and personalized information. Thus, they will receive SMS that contains a phone number to contact the DSO and get more precise information as soon as a certain number of interrupted customers are reached. The municipalities can decide the threshold number of affected customers and the duration of interruption. [18]

At present the customers can get individual information about the outage by entering his zip code on the DSO's website. In future, different customer groups like telecommunication companies and big industrial grid customers could be added. The system will be further developed so that the social networks could be used to gain information about the outages and to distribute the information. [18]

C. Finland

In Finland, some improvements have been done to solve the observed problems with inter-organizational SA in the major disturbances of electricity supply. The most of the Finnish DSOs inform about their outages in their website. Some of them are map based systems and some are in text format. In this chapter two highly developed systems are presented.

DSO Elenia (former Vattenfall) offers different SA services to their customers and fire and rescue services in Finland. For customers, Elenia offers SMS service and map service in their website. These services have been developed

because customers have been requesting some improvement to informing them about the outages. The outage information offered by the services is produced in DMS. DMS takes information from a Supervisory Control and Data Acquisition system (SCADA) or Automatic Meter Reading (AMR). The outage information is linked to information from the customer information system. This helps to solve which customers are affected on outage. All services are produced by a multichannel communication system (MCS). SMS or email service can be subscribed to in DSO's website. The service is provided on two levels: basic and extended. At both levels, the message includes information about sustained faults and planned interruptions. Information about outage's beginning time, status information and ending is delivered on both services. The extended service includes also messages about momentary interruptions. DSO has offered the outage map in their website since 2007, and the SMS service since 2008. After developing these, Elenia has begun to offer a service to their customers where customer can send information and photos about outage situation with mobile phone app. [19],[20]

In the cooperative workshop of this research it has been occurred that after 2011 storms, Elenia started to offer DMS service to fire and rescue departments whose responsible working area is in Elenia's network area. This development process bases partly on this research. The DMS service brought to fire and rescue departments bases on the same system that is earlier developed to give information to network repairers, presented in [21]. Real time operational and switching state of the whole network can be seen with this service. It is offered to improve fire and rescue departments' SA of the disturbances of electricity supply. In addition to this service, a representative from fire and rescue services has been following the disturbances in DSO's operation room as a connect person in some disturbances.

Another system used in Finland is Gridwise. It is a SA system offered to DSOs. In Finland, DSO Savon Voima is using this service. The system offers information to DSO themselves and to their customers. The Gridwise merges information from DSO's own systems, weather forecast and fire and rescue services tasks. Gridwise has been developed for fulfilling the demands that new Electricity market act in Finland sets concerning DSO's participating in the formation of a situational awareness and supply information relevant to this purpose to the responsible authorities. The system can be used via webpage. The Gridwise service can be built from different modules based on the customer needs. There are different functions for DSOs, customers and authorities. [22]

V. COMPARISON OF THE SA SYSTEMS

Based on the published information a comparison of above systems has been created. The comparison is focused on the main motivations, technical execution and details and users of the system. When the concept of inter-organizational SA began to be developed in this research, there were no other inter-organizational SA systems available. The meaning of the comparison is to find if there are similarities and differences with the systems. The results of the comparison are presented in table I.

TABLE I. COMPARISON OF THE SA SYSTEMS

		CIOSAS	MASAS	SiRena	PRONET SIS	Elenia services	GridWise
Basic use of the system	Disturbances of electricity network	x		x	x	x	x
	Emergency situations	x*	x				
Motivation	Legislation or Government		x				x
	Customers' wish					x	
	Other actors' wish	x		x	x		
Completeness	In use				x	x	x
	Pilot (in use)		x	x			
	Demonstration or project	x					
Technical execution	Peer-to-peer				x	x	x
	Hub based	x	x	x			
Communication method	Map	x	x	x	x	x	x
	Chart	x	x	x	x	x	x
	Phone call				x		
	Sms	x		x	x	x	x
	Email				x	x	
	Video		x				
	Possibility to input picture/photo		x	x		x	x
	Chat			x			
Specific database for SA use	Criticality information	x					
	Resources			x			
Administration	Commercial/DSO				x	x	x
	Government		x				
	University	x		x			
User groups	Authorities (e.g. fire and rescue, police)	x	x	x	x	x	x
	Electricity distribution system operators	x	x	x	x	x	x
	Emergency management		x		x		
	Rescue/emergency response centre	x	x		x		
	Government		x	x			
	Municipalities	x	x		x		
	Voluntary services	x	x				
	Citizens	x	x	x		x	x
	Companies		x		x	x	x
Media	x	x			x	x	

*The concept of CIOSAS offers a possibility to extend it to concern disturbances of the other critical infrastructures

Most of the systems have been developed straight to the cases of disturbances of electricity supply. Only MASAS is meant for all emergency situations. However, the concept of CIOSAS is developed so that it can be extended to the use of the disturbances of other infrastructures.

The motivation for developing the systems varies. In Finland there is a new legislation which demands inter-organizational SA in major disturbances and that has been a driver for the GridWise project. This change in legislation has also affected the CIOSAS development process. The situation of MASAS reminds the situation in Finland, because in Canada the government has been the driver for the development project. Other system's drivers have been mainly wishes from the customers or from the other actors.

The technical execution of the systems can be divided on two different main categories: peer-to-peer approach and hub based architecture. An interesting detail is that those systems

that are already in use are all peer-to-peer systems. Two of the hub based systems are in pilot use and our system is still at demonstration level. However, like in CIOSAS, hub based method enables the possibility to get information from multiple DSOs to the same system. This improves of getting the SA of widespread disturbance situation at once. This feature is not in use in any of the present used systems.

The methods, that systems use to present the information varies some. However, common to all of them is to use maps and charts. CIOSAS has quite few presentation methods compared whit others. It is common for every Finnish system.

The main difference that CIOSAS has to the others is the criticality database. The database is meant to gather information about targets that needs electricity to maintain people lives, and about their ability to maintain their actions without electricity. Only other system that has specific

database in use for SA is SiRena, which has a database for available resources.

The administration of the systems seems to be related to the completeness of the systems. Those systems that are already in use are maintained by DSOs. Those which are still in pilot or demonstration state are maintained by either university or government.

The most variation between the systems is in user groups of the system. MASAS is meant for every actor and citizens affected the emergency situation. The other systems all have DSOs and authorities in part of their user groups. Most of the systems offer something also to the citizens. Some of this variation can be because of there is different kind of emergency organization structure in every country e.g. in Finland, there is no special emergency management actor.

VI. CONCLUSION

Lack of information exchange in the major disturbances of electricity supply has been noticed in many researches. Present methods are inadequate. Some inter-organizational SA systems have been developed in recently to the emergency and the disturbance of electricity supply situations. The concept presented in this research resembles the other systems that have been developed.

The main commonality between the studied systems is the variety of the presentation methods. The other common thing was that the DSOs and authorities are always part of the user groups.

From the comparison it can be seen that those systems that have been administered by DSOs have been taken in use already. This could mean that taking a commercial approach could be the most effective way to execute the inter-organizational SA system. However, in that case there is possibility that some important elements will be missing, because of the rush. Most of the commercial ones had less user groups than other systems.

The CIOSAS system developed in this research resembles mostly the other systems developed in Finland. Comparing with other Finnish systems, CIOSAS is only one using the hub based architecture, which enables bringing information about disturbance from several DSOs to the same system. The main difference to all of the other systems is that, CIOSAS brings criticality information to DSO and other actors. CIOSAS can also be extended to cover other emergency situations unlike systems designed only for the disturbances of electricity supply. The weakness in CIOSAS is that it is a demonstration for now and not in use yet.

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Publication V

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DEMONSTRATION OF THE INTER-ORGANIZATIONAL SITUATION AWARENESS SYSTEM TO MAJOR DISTURBANCES

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ABSTRACT

There have been several problems in information exchange between organizations in the disturbances of the electricity supply. For instance, in Finland one municipality had problems to reach their local DSO (Distribution System Operator) during a disturbance in 2011. They had only the phone number of the DSO's customer service, which was congested. Usually in disturbances, municipalities and authorities receive information from DSOs' web pages, like transformer level maps or lists that show the outages and their duration, and by phone conversations. In general, it can be said that the inter-organizational situation awareness in disturbance situations is needed. After the storms in Finland in December 2011 the Finnish Electricity Market act was changed so that DSOs should participate in the formation of situation awareness and supply any information relevant to this purpose to the responsible authorities.

The paper presents a demonstration of the inter-organizational situation awareness system developed in this research. The demonstration consists of an internet service which combines information about disturbances in the electricity supply from DSOs' information systems and information from other actors. The demonstration illustrates how the exchange of information between actors can be executed by using a situation awareness system. It extends the integration of DMS (Distribution Management System) in an unusual direction by taking the other actors into account.

INTRODUCTION

There have been several problems in the information exchange between organizations in disturbances of electricity supply. Usually in disturbances, municipalities and authorities receive information from DSOs' web pages, like transformer level maps or lists that show the outages and their duration and by phone conversations. Most of the time the information is shattered and poorly processed. The problems that municipalities and fire and rescue services have in disturbances are just a tip of the iceberg. [1]

Storms like Pyry and Janika in Finland in 2001, Gudrun 2005 and Per 2006 in Sweden, four storms in the summer of 2010, storms at Christmas 2011 and two storms in the autumn of 2013 in Finland, caused widespread and long

lasting disturbances of electricity supply. In those storms, some individual customers were without electricity for a few weeks. In January 2011 and January 2015 snow load on trees caused widespread and long lasting disturbances in Finland. In addition to storms that affect the rural area, the hurricane Sandy caused widespread disturbances in Eastern parts of the USA in October 2012 including some cities. There were e.g. floods that caused outage to Manhattan in New York. [1]-[9]

Typically, the disturbances caused problems in telecommunication, water supply, animals' conditions in farms and with the coldness in private houses. The coldness of the houses has led to even some evacuations. The problems with telecommunication effected also to safety phones and buttons. [1]-[9]

After the storms in Finland in December 2011, the Finnish Electricity Market act was changed in order to mitigate the risk of major disturbance both by reducing their probability and by improving their management. One addition to legislation was that DSOs should participate in the formation of the situation awareness and supply any information relevant to this purpose to the responsible authorities. However, the law itself does not define what relevant information actually means and how the information should be delivered. [10]

In this research, a major disturbance of electricity supply was defined as *a long lasting or widespread interruption in the supply of electric power, during which the fire and rescue services and one or more other public actor (municipality, police, etc.) need, in addition to the distribution system operator (DSO), to start implementing measures for reducing possible severe consequences to people and property.* [3]

In major disturbances, there are multiple actors involved, like DSOs, contractors, fire and rescue services, emergency response centres, police, municipalities, voluntary organizations and customers. All the actors are obligated to maintain their capability to carry out their duties related to major disturbance. Major disturbances cause them also more duties e.g. fire and rescue services help people out from the elevators and municipalities arrange evacuations and check if elderly people need help. [3]

In similar studies, they have noticed several problems with inter-organizational situation awareness in major disturbances in Germany. There are problems with distributed information, missing awareness about available information, policy issues of information, handling the uncertainties of information, terminology

issues and perceiving interdependencies between information. The policy issues and workload issues prefer that there is no need for common awareness for every actor. Instead shared information should be individualized or localized. The same issues have been noticed also in Finland. [1]-[5],[11],[12]

This paper presents results based on research done by the Tampere University of Technology. In this research a demonstration of the situation awareness system has been developed to improve inter-organizational situation awareness. Demonstration consists of an internet service which combines information about disturbances of the electricity supply from DSOs' information systems and information from other actors. The demonstration illustrates how the exchange of information between actors could be executed by using a situation awareness system. In addition to present ways, the demonstration has a database which contains information of customers highly dependent on electricity.

PRESENT INTER-ORGANIZATIONAL SITUATION AWARENESS SYSTEMS

When the concept of the demonstration was developed in this research, there was no similar concept of an inter-organizational situation awareness system for the major disturbances of electricity supply. However, some DSOs offer information about outage on their webpage. Recently, several situation awareness systems that can be used for disturbances of electricity supply have been published. Some of them are designed only for disturbances of electricity supply and some are situation awareness systems for emergency situations. [1]

In Finland, some DSOs offer SMS (Short Message Service) service and map service in their website for the customers. Usually, these methods give information about outage's beginning time, status information and ending. SMS service informs only about outages that effect on the customers' own sites. In addition, some DSOs offer the DMS service for their local fire and rescue services. These services give the view access to the DMS for the authority in disturbances. One DSO's service bases on the system that was earlier developed for network repairers. In addition, some DSOs have mobile apps which a customer can use for sending a picture about possible fault place in network. The fault place can be located from the location information of the picture. [1], [13]-[15]

In Germany, there are also few situation awareness systems developed for disturbances of electricity supply. DSO MITNETZ STROM has developed a system which delivers information about outages to authorities. For the rescue coordination centres the system sends email, which can be integrated in to their system. Municipalities receive SMS which includes DSO's phone number. [1], [12]

The other project in Germany is Infostrom, where they have developed "Sicherheitsarena" (SiRena) system to help information exchange between different actors in disturbances. The system is based on a digital map and a

resource repository. It allows adding different types of internal and external information e.g. place marks, new information resources and weather information. In addition, users have opportunity to show and hide information resources from the map. [1],[16],[17]

In Canada, the Multi-Agency Situational Awareness System (MASAS) has been developed for exchanging emergency management incident relevant information between multiple agencies and jurisdictions. It is used as the national situation awareness system for emergency management of Canada. The MASAS can be used for sharing information in disturbances of electricity supply even though it is not designed specifically for that. Users of MASAS can be representatives e.g. of municipal, provincial, territorial and federal and emergency management, police, fire and rescue services and infrastructures. The architecture of the system is hub based so that the amount of the interfaces could be minimized. [18],[19]

The main commonality between the above systems is the variety of the presentation methods. The other common thing is that the DSOs and authorities are always part of the user groups. The common for all present ways to offer the information in disturbances is that there are only a few bidirectional functions on these systems. In addition, present ways are not usually personalized to different user groups. [1]

INTEGRATION OF DISTRIBUTION MANAGEMENT SYSTEM

The integration of DSO's information systems are constantly evolving. At present, integration use mainly point to point architecture. The evolution of the electricity network towards the Smart Grid has increased the amount of the ICT (Information and Communications Technology) in the network. This makes integration too complex. The amount of data exchange between participating parties and components inside a Smart Grid ecosystem and the requirement for system openness has caused need for standardization. [20],[21]

In standards IEC 61968 and IEC 61970, the integration of DMS is defined like presented in the interface reference model in Figure 1. The model is focused mainly on the integration of the DSO's own systems and pre-defined interfaces between DMS and automation parts. However, this model does not include information exchange between different actors which have been noticed to be crucial for managing the disturbance situations. [1],[20]

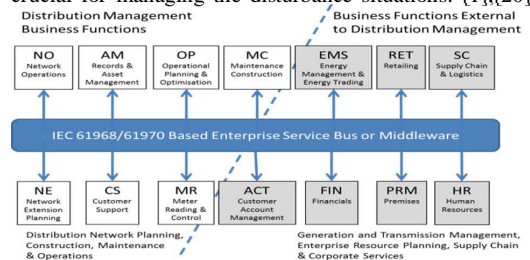


Figure 1. Interface reference model [20]

THE DEMONSTRATION OF SITUATION AWARENESS SYSTEM

The concept

The demonstration has been developed based on the cooperative workshops of the research and user need interviews. The development process has been iterative and the results of the interviews have been taken account in the development.

Two fire and rescue services and one municipality were interviewed to clarify the user needs of the system. The main results in the interviews were that the authorities need information from all DSOs which are operating in their operation area. The fire and rescue services want a simple view, where they can quickly get an overall awareness of the disturbance situation. All interviewees expect possibility to deliver information also back to DSOs. The results from the interviews were taken into account while developing the demonstration.

In the concept of the demonstration (Figure 2), all information related to the disturbance is gathered to one system. The information can be e.g. outages of electricity supply or telecommunication, weather forecasts and traffic reports. A new feature compared with the existing systems is that it is possible to bring information about outages to the demonstration from multiple DSOs and telecommunication operators.

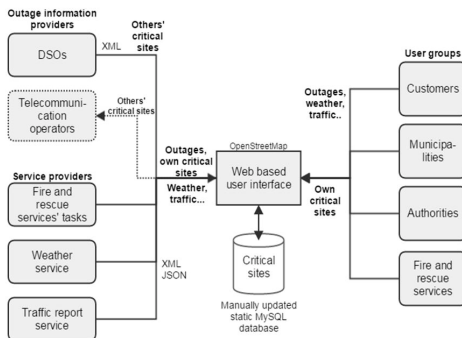


Figure 2. Structure of the demonstration

The demonstration has a web based user interface which shows outages on the map (Figure 3). It offers a personalized view to different user groups based on their needs of information. It enables user to filter information shown on map with different layers e.g. municipality can choose a layer of all citizens who are older than 70 years. OpenStreetMap is used as a base of the user interface. However, it can be easily changed to some other map service like Google Maps.

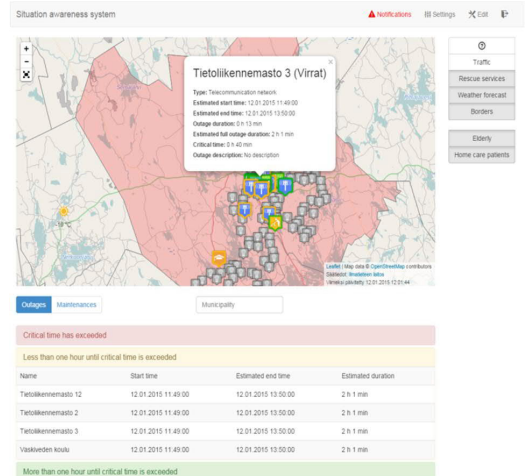


Figure 3. User interface of the demonstration

The demonstration enables the filtering of the information from the users' own operation area. The outage information from different DMSs is brought to the web service where it is combined. From the user interface, the user can observe either the whole situation or they can choose an area of one municipality (Figure 4).

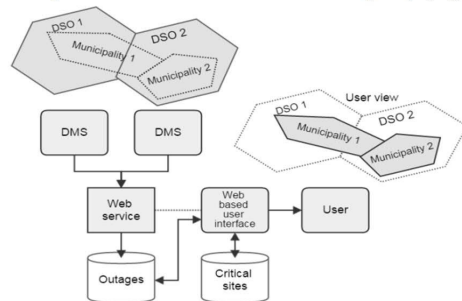


Figure 4. Filtering the user's own operating area

The demonstration brings new information compared with the present systems, by adding the so called critical sites database. Users can add their critical sites, which are highly dependent on electricity to the critical database. The authorities and DSOs can see all critical sites while critical customers can see only their own sites. In addition the demonstration enables bidirectional information exchange to actors. This enables DSOs to have an updated database of critical sites locally allowing them to direct restoring actions to critical sites.

The demonstration resembles the other systems developed in Finland. However, compared with the existing systems the demonstration enables bringing information about disturbance from several DSOs to the same system. The demonstration can also be extended to cover other emergency situations unlike most of the systems designed only for the disturbances of electricity supply. [1]

Criticality database

The main feature of the demonstration developed in this research is the criticality database. It is a MySQL database which has information about sites that are highly dependent on electricity. These sites can be for example hospitals, home care patients and critical infrastructures. The information from the database helps DSOs to decide the restoring order in major disturbances of electricity supply. The information can be used also for network planning. In addition, the other actors can use the information to help these sites.

The users maintain information about their own sites. The information is fed when the site is created in the system and it can be changed whenever wanted. The criticality database includes information about how long the critical site will manage without electricity so that there will not be any severe consequences to people or property. The seriousness of the consequences if the critical time is exceeded is also found from the database. If the critical site has a backup power generator, it has been taken into account when deciding the critical time. In addition, critical sites are grouped by their type.

The information from the critical database is used to present the critical sites on the map interface with different symbols by their type. The size of the symbol is dependent of the given consequences. The critical time is presented by frames that have traffic light colouring. Frames are always green if there is at least one hour left to critical time exceed. When there is one hour or less, the frame is yellow. After the critical time has exceeded the frame turns to red. The colouring system will help the user to notice those sites that need electricity or evacuation mostly.

Technical Execution of the Demonstration

The execution of the demonstration bases on the existing systems and methods, which DSOs use with their web pages and SMS services. The demonstration uses two types of outage information that DMS generates. Transformer level information is generated every time a change of state happens in the network. When a change occurs, the DMS generates an XML (Extensible Markup Language) file with information about the entire network. A proxy application watches changes in the file and sends the outage information to the situation awareness system every time the file changes. The outage information can be sent using multiple protocols. The outage data upload can be done using any of the commonly used data transfer protocols such as FTP (File Transfer Protocol) and HTTP (HyperText Transfer Protocol). A local file copy can be performed if the system and the DMS are running on the same server. The generated XML file format can be seen in Figure 5.

```
<outage ID="1" type="fault" start="14.05.2014 07:15"
end="14.05.2014 15:31" desc="Equipment failure.">
<station code="1" lat="00.000000"
lng="00.000000" area="North" customers="15"/>
</outage>
```

Figure 5. The generated XML outage information file format

The XML file contains information about each outage on

the network (start time, end time, type and description) and about each transformer station in the outage. The station attribute area is an area defined in the DMS. The data is generic and customers can only be identified if the customer transformer code is known. The data format may slightly change between DMSs from different vendors. In such case, the proxy application parses the file and creates a file using a unified format.

The DMS also generates outage information in level of customer identification number. This data is normally used for sending SMS messages to clients in outage areas. Each outage information message has information about the outage (such as certainty, state and reason) and a list of customers the outage affects. The DMS implements a SOAP (Simple Object Access Protocol) client that connects to the proxy application implementing SOAP server interface. The DMS sends data to proxy application whenever a change in outage state occurs. The data is parsed and forwarded to the situation awareness system using HTTPS-protocol (HyperText Transfer Protocol Secure). The outage information is then saved into a database. The transformer level and customer level outage information is used to identify critical customers by either transformer code or customer number.

While it is important for municipalities and fire and rescue services to be aware of where the critical customers are it is also important for the DSOs to know where the critical sites are. This is why an interface for getting the critical site information from the system is implemented. Using this interface a DSO can keep information about customers' criticality updated without having to commit many resources to it. The interface is a simple HTTPS API that requires HTTP Basic authentication. DSOs can use this API to list all critical sites added by other users. In addition, the list can be filtered e.g. to list sites which are added since a defined time.

CONCLUSION

Lack of information exchange in the major disturbances of electricity supply has been noticed in many researches. The interface reference model of DMS, presented in standards IEC 61968 and IEC 61970, is inadequate in disturbances, because it is focused mainly on the integration of the DSOs' own systems and it does not enable information exchange between multiple actors.

Some inter-organizational situation awareness systems have been developed in recently to the emergency and the disturbance of electricity supply situations. The demonstration presented in this research resembles the other systems that have been developed. The main difference to the present systems is that, the demonstration presented here brings criticality information to DSO and other actors.

The results of the user needs interviews done in this research were that authorities need awareness of the disturbance situation from their own operating area and they need more bidirectional information exchange.

Usually it means that the information from multiple DSOs has to be combined. The demonstration presented in this paper is developed to fulfil these needs.

FURTHER STUDIES

The developed concept covers the communication between actors in disturbances of electricity supply and further it will be extended to cover disturbances of telecommunications. This combination of information from both networks disturbances can be utilized in maintaining the reliability of both networks and in planning them.

In future, the developed system should be tested in a few different cases e.g. with the social care of the municipality and DSO could be users for the system. Testing could be arranged as a part of emergency drill or disturbance exercise.

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Publication VI

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Combined Electricity and Mobile Network Situation Awareness System for Disturbance Management

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Abstract—In this research, a demonstration of a situation awareness system is presented. A real case of the disturbance of the electricity network was illustrated with the demonstration. The state of the remote controlled switches was simulated based on the model of the mobile network coverage and compared with the real state information from the online remote field service provider. The case study confirmed that there are interdependencies between both networks. The main contribution of this research is a new method to improve the disturbance management of electricity and mobile networks and to improve the resilience of the society in disturbances by a combined situation awareness system.

Index Terms—Disturbance, Situation awareness, Co-operation, Mobile network, Remote controlled switch.

I. INTRODUCTION

There have been several problems in the information exchange between organizations in disturbances of electricity supply. Interdependencies between electricity and mobile networks have been noticed. The situation where both electricity and mobile network have an interruption at the same time is complex to manage.

Storms like Pyry and Janika in Finland in 2001, Gudrun 2005 and Per 2006 in Sweden, four storms in the summer of 2010, storms at Christmas of 2011 and two storms in autumn of 2013 in Finland caused widespread and long lasting disturbances in the supply of electric power. In those storms, some individual customers were without electricity for a few weeks. In January of 2011 snow load on trees caused widespread disturbances in Finland. In addition to storms that affect the rural area, the hurricane Sandy caused widespread disturbances in Eastern parts of the USA in October of 2012 including some cities. There were e.g. floods that caused outages in Manhattan, New York. [1]-[7]

Many of the long lasting and wide spread disturbances, the so called major disturbances, are induced by storms and other severe weather conditions. However there have also been

major disturbances that have not been especially long lasting but extremely wide spread, like the disturbances in the transmission systems in the USA and Canada in 2003 and in Central Europe in 2006. Both of these caused negative societal consequences. [1]-[7]

Typically, the disturbances caused problems in telecommunication, water supply, animals' conditions in farms and with the coldness in private houses. The coldness of the houses has even resulted in some evacuations. The problems with telecommunication also affected safety phones and safety buttons. [1]-[7]

Electricity distribution and mobile networks are interdependent. Mobile network base stations require electricity to operate. The base stations should have backup power batteries or other reserve power to maintain the transmission for at least three hours assigned by The Finnish Communications Regulatory Authority (FICORA). However, the electricity disturbance can last longer than the reserve backup power, e.g. because of storms. [8]-[10]

While the electricity network can operate without telecommunications for the operation of the distribution automation (DA) it is necessary. Traditionally most of the communication was done using proprietary communication methods and protocols. Nowadays the mobile network is utilized in multiple ways in distribution networks such as DA and communication with repair groups. [11], [12]

The electricity network is developing towards the Smart Grid, thus the amount of DA devices in the distribution network has increased in recent years. DA devices improve the outage recover times. Previously, a telecommunication link was only established to critical parts of the network such as substations. After a remote connection to substations, the utilization of remote controlled disconnectors started. Nowadays in addition to these devices a connection is also needed for automatic meter reading (AMR). The connection between control center and DA devices is often based on mobile network technologies. Powerline communication

(PLC) is also used together with a mobile network (e.g. for AMR meters). These connections also depend on the mobile network as part of the communication link to the control center is implemented using a mobile network. [12], [13]

In addition to remotely controlled devices, Distribution System Operator (DSO) relies on mobile networks to contact and follow repair teams and subcontractors during disturbances. If both actors receive information about these disturbances, their recovery processes could be executed more efficiently.

After the storms in Finland in December 2011 the Finnish Electricity Market act was changed to improve the reliability of the electricity networks. The new addition to the legislation requires DSO to prepare a contingency plan for disturbances. Further, it was added to the legislation that the maximum duration to outage will be six hours in urban areas and 36 hours in rural areas concerning all of the customers from the beginning of 2029. DSOs must prepare development plans to describe how these limits will be achieved and how the electricity supply for the sites that are important to the resilience of the society are ensured. Further, the new legislation requires that the DSOs should participate in the formation of a situational awareness and supply any information relevant to this purpose to the responsible authorities. [14]

This paper presents the demonstration of a situation awareness system that combines information about interruptions of electricity and mobile networks. This system can be utilized to improve the resilience of both networks. Further, a case in which an interruption occurred in both networks has been studied.

II. METHODS

A demonstration of inter-organizational situation awareness system to disturbances of electricity supply has been developed in this research. The developing process has been iterative. The present situation has been studied by literature review and in several cooperative workshops of this research. These results are presented in [1]-[3]. Methods of the usability and user-centered design have been utilized in the design process to improve the demonstration e.g. semi-structured interviews for user needs [14], [15].

In this paper, the main focus is in instrumental case study approach [16]. The case has been simulated with the developed demonstration and compared with the real life case. The results of the comparison were analyzed for studying the capability to utilize the demonstration to improve the restoration process of the electricity networks and mobile networks.

III. THE SOURCES OF THE SITUATION AWARENESS IN DISTURBANCES

Endsley's theory of the three levelled situation awareness is utilized in design process of the system. The theory defines the situation awareness (SA) as the triad of "perception", "comprehension" and "projection". The first level consists of perception of the status, attributes and dynamics relevant elements in the environment of the situation. At the second,

level the comprehension of the situation is formed based on the information received at the first level. At the third level, the perception and comprehension are utilized to form a projection of the future happenings in the situation. [15], [17], [18]

DSO's situation awareness can be divided into two categories; internal and external (Fig 1). At present, the studies of DSO's SA are focused internal SA. Thus, the information systems that DSO utilizes are focused to support mainly on that. These systems are SCADA, Distribution Management System (DMS), work management system (WMS) and customer information system (CIS). All of these are designed to support the everyday actions of DSO. [19]-[21]

SCADA collects the status and measurement data from the network. This information is used to control the network. DMS connects data from SCADA and customer information system to map-based user interface. With DMS the overall picture about the network can be seen. It can be used to plan and remake the connections in the network. At disturbance situation DMS is important tool to locate the outages and to get an overall awareness of the situation. In addition, the WMS is an important tool in disturbances, thus it is utilized to locate the repairer teams and to communicate with them. It can be utilized to share tasks and send teams to right places to fix faults. [21]

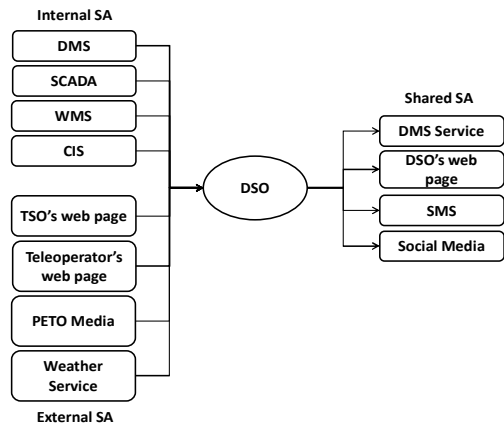


Figure 1. The DSO's situation awareness.

The external situation awareness of DSO can be divided to the information that DSO delivers to other actors and customers and to the information that DSO receives from others. The main information that DSO needs is the situation of transmission network, because the issues in transmission network can affect the distribution network. Some of the DSOs want to follow the outages of their neighbour DSOs' networks. By following that information, DSO can predict if storm is coming to their operating area. However, public web pages are the only way to follow the other DSOs. In addition to their systems DSO gets weather forecast and warnings from local meteorological institute. Other information that DSO receives can be e.g. tasks of fire and rescue services. [1]

Some DSOs are co-operating with their local mobile network operators and they may have information about the locations of the important mobile network base stations. In addition, they may follow the coverage information of the mobile network from operator's public web page. In Finland, the mobile network operators are offering information about their interruptions on a digital map. There are no restrictions about how accurate level the information has to be illustrated, thus some operators are offering information in municipality level while others are offering it in more detailed level. For the purpose of the DSO this information is often too inaccurate.

Some DSOs are maintaining a database about customers that are highly dependent on electricity. However, this information is usually outdated because there are no established practices. [1], [2]

At present, the information that DSO shares to others is focused mainly on their web pages. Most of the DSOs in Finland have an outage map on their web page. Users can utilize the outage map to see which areas the outage affects (in transformer level accuracy), when it has started, when it is estimated to end and how many customers it affects. This information comes from DSO's DMS. Some DSOs utilize DMS also to share more detailed information to repairers, subcontractors and fire and rescue services. This so called DMS service was originally designed to share information to subcontractors and it is a direct view to DMS. Technical language is used in the interface and can be difficult to use by the fire and rescue service. In addition, some DSOs have SMS services that send the outage start time, estimated duration and the estimated end time information to the customer. [22], [23]

In Finland, there are three main mobile network operators who have their own infrastructure. Their operating areas are wider than DSO's, i.e. nationwide. There are multiple DSOs in area of one mobile network operator. The mobile network operators are not offered any additional services i.e. DMS service by DSOs, thus they are relying on public web pages of DSOs. Consequence of this is that the information that mobile network operators achieve from the disturbances of the electricity network is shattered to multiple systems.

There are some Situation Awareness (SA) systems available for the disturbances of electricity supply. Some of them are designed especially for disturbances of electricity supply and some for common emergency situations. Common for those systems are that they are focused on level 1 and 2 SA and do not process different information to give the projection to future. [20]-[26]

IV. THE DEMONSTRATION OF SITUATION AWARENESS SYSTEM

The problem with present sources of the situation awareness is that the interdependency between electricity and mobile network has not been taken into consideration. None of the systems combines information of the both networks. Furthermore, the devices that are dependent on both networks are not included in present systems. [1], [2]

In this study, the demonstration of a situation awareness system to disturbances of electricity supply has been

developed. This demonstration consists of two parts; 1) first part illustrates the mobile network coverage and base stations, 2) the second part illustrates the information from different actors related in disturbance e.g. fire and rescue services tasks. The demonstration combines information from multiple DSOs and mobile network operators to web based user interface. In addition, information about remote controlled devices can be added to the system. The system structure is presented in Fig. 2.

The main users are distribution system operators and mobile operators. In addition, municipalities, authorities and fire and rescue services can benefit on it. The demonstration can be personalized by organizations.

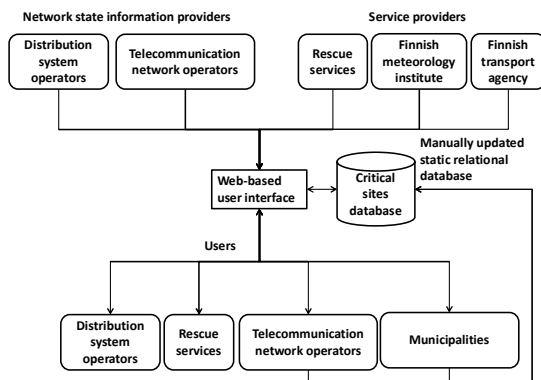


Figure 2. The diagram of the demonstration.

This demonstration presents combined information from both networks (Fig. 3). The gray symbol indicates the transformer station which has an outage and the red polygon indicates the lack of mobile network coverage. In addition, mobile network base stations have their own symbol. The color of the base station symbol informs if the base station does not have electricity or if it runs on batteries. It is marked with a blue symbol when the situation is normal. If a base station has to rely on batteries, the color of the symbol is yellow, and if it does not have any electricity supply the color of the symbol is red.

In addition, there is a symbol for the repair team and remote controlled switches. The location information of the repair team can be combined with coverage information to achieve information if the repair team is approaching an area without coverage. Remote controlled switches are presented with a white symbol if they do not have mobile network coverage. Otherwise they have light blue symbols.

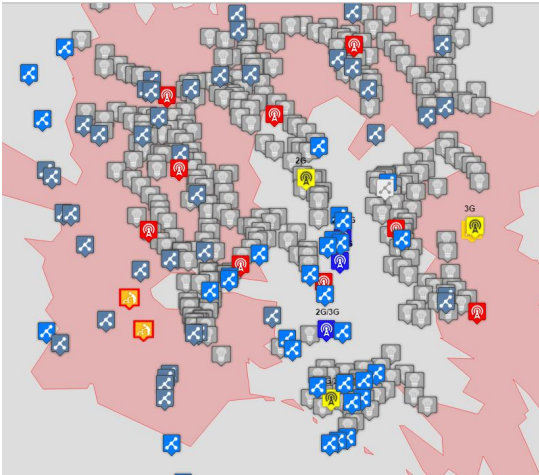


Figure 3. A view of the system.

The public authorities can add information about their own critical sites such as people with safety phones to the system. These sites are presented with their own symbols (orange symbol in Fig. 3). The symbol of such critical site will show if there is no electricity or mobile network coverage.

V. THE CASE STUDY - THE REMOTE CONTROLLED SWITCHES

An outage case that occurred in Finland was studied in this research. Information about the case was received from multiple organizations. The DSO provided transformer status information about the area. The mobile network operator provided configuration and status information about the mobile network base stations. An online remote field service provider provided information about the communication link statuses of the switches in the electricity network.

The provided base station configuration data was used to simulate the coverage areas of each base station. The coverage areas have been accurately simulated with a mobile network simulation taking into account all necessary configuration parameters. These parameters include base station locations, antenna heights, antenna directions, antenna tilting, antenna models and their gains, transmission powers and any additional losses as well as the used frequencies for Global System for Mobile Communications (GSM) and Universal Mobile Telecommunications System (UMTS) systems. In addition, Okumura-Hata path loss model was used to calculate the overall signal power loss of the propagated signal from a transmitter to receiver, also taking into account the effect of the elevation differences in the area. The simulation results were exported separately for each base station site as images to visualize the coverage areas.

The base station data has been visualized on the map with the coverage areas and the status information. The mobile network operator provided the information whether the base station was active or not. No information was provided on whether the station is supplied by the network or by the

backup battery. A simple model is used: whenever the nearest transformer is affected by the outage, the base station is being supplied by the backup battery.

In addition third party remote controlled switch statuses were displayed on the map. The status of a switch is either on or off. The switch mainly used the network of the mobile network operator that provided the mobile network data. If the switch is on, the packet loss is 0 %. If the switch is off, the packet loss is 100 %. The modelled coverage areas are used to calculate a modelled status for each switch based on their location in the coverage area. Both the modelled and the actual status are then displayed on the view.

The example of the system's view is shown in figure 3. The blue symbols present mobile network base stations that are being supplied by the network. The yellow symbols present mobile network base stations that are possibly being supplied by a backup battery. The red symbols present mobile network base stations that are down. The bright blue symbols present remote controlled switch that have a working telecommunication link. Similar white symbols present remote controlled switch without a working telecommunication link. Similar grey symbols present remote switch that are modelled to not have a working telecommunication link but actually have one. The differences in the model and the real state are discussed in the next chapter.

VI. THE RESULTS OF THE CASE STUDY

In the studied case, the storm caused interruption to electricity network. Because of the storm, the interruption in electricity network expanded gradually. The base stations of the mobile network have backup power, thus the interruption did not effect on mobile network and switches immediately. Based on the modelled situation of the mobile network, the first switches (grey symbol in Fig. 4) became unreachable 2 hours earlier than in the real case

When the worst situation occurred in the mobile network, the worst situation from the switch point of view began. There were 103 switches in the studied interruption area. In the worst case 12 switches were unreachable (Fig. 4). This happened approximately 4 hours after the first failure in the electricity network. After this the situation was improving when the base station in south-west of the observed area was restored. However, 9 hours after the beginning of the interruption, more switches started to become unreachable even though the mobile network was already operating in the area. In this case, the dropped switches were located to the edge of the studied area. Approximately 12 hours after the beginning of the interruption all switches were fully functioning.

In the model, the amount of the switches that did not function was bigger than in real case. 63 switches were unreachable in the worst case in the model. In addition, the timing of the worst situation did not match to real case. In the last drop of the switches, the modelled values resembled the real data.

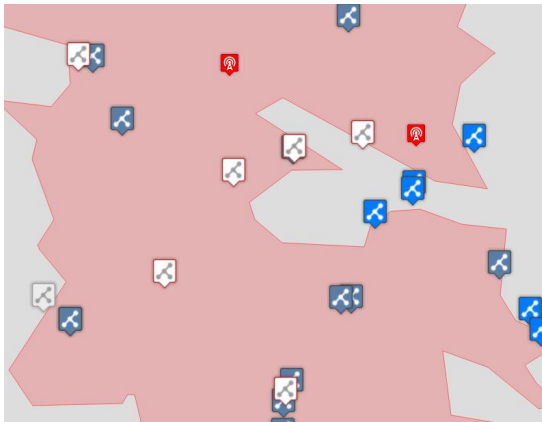


Figure 4. The worst situation in the observed case.

VII. DISCUSSION

The data about remote controlled devices illustrated in the system, was analyzed to utilize the demonstration to improve the restoration process of the both network was studied. Information about the modelled status of the switches and the real status of the switches were compared. There are some differences in the statuses especially in the edges of the observed area.

There were some issues with the information as the observed areas were slightly different. Some of the differences between modelled and real status can be caused by the 10 minute status polling time of switches.

If the data is observed only from the mobile network coverage point of view, it can be said that the modelled and measured statuses do not match. There can be several reasons for that. First, the coverage area has only been generated from a specific area and does not include the coverages of the surrounding base stations. The coverages usually overlap and can improve the service in the edges of the current observed area. Second, the switches could utilize two operators' mobile networks. However, in this case all the switches were using the same mobile network. If the comparison is made in the middle of the modelled area, the model and the real data resemble each other. The most probable reason for this is that that modelled mobile network area is too small. A larger area should have been modelled.

9 hours after the beginning of the disturbances 10 switches became unreachable while there was mobile network coverage in the area. There is a small chance that the devices do not have electricity and their backup power was lost. However, the chance is quite small, because the backup batteries are designed to last at least 24 hours. The other option is that the mobile network coverage simulations are incorrect on that location. However, the switches are located in the area where everything else is working.

The studied remote controlled switches utilize the network of one mobile operator. Their resilience could be improved by

utilizing networks of multiple operators. However, in Finland mobile operators are using common masts often, thus if the interruption in electricity network is affecting one mobile network it is most likely affecting the others too.

Based on the analysis of the case, the situation awareness system can be utilized to find the interdependencies between electricity network and mobile network. Further, this information can be utilized in the restoration planning of both networks. With the system the DSO and the mobile network operator can locate the most important base stations in the electricity network. The DSO can utilize the information to restore the electricity first to those base stations, thus achieving communication to their own remote controlled devices. The mobile network operator can utilize the information to locate the transferable backup generation to the base stations that are most important for DSO's communication. In addition, if the interruption information is combined with the information of how long the base station has backup power it can be utilized to project the future events of both networks.

The DSO can utilize the information about the coverage area of the mobile network to inform their repair teams about the problems in communication, e.g. the repair team can be warned if they are approaching an area with no coverage.

Further, the system can be utilized when developing both networks. The DSO can ensure the supply to the most important base stations e.g. by cabling. Likewise, the mobile network operator can improve the backup of the important base stations.

The public authorities can utilize the system to follow their own sites that are critically dependent on electricity or mobile network e.g. safety phone customers. With this information they can focus their actions better. In addition, the simulation part of the system can be utilized for training purpose.

For further development the methods utilized in the demonstration will be applied into a live demonstration. The demonstration presented above is an offline demonstration of a previous disturbance. In the live demonstration the mobile and electricity network data is gathered in real time, the data is combined and the current situation is shown on the web based user interface. Users such as the mobile network operator, the DSO and municipalities can use the system during the live demonstration to gain information about the current situation in the electricity and mobile networks. Different situation awareness rating and testing methods can be utilized to study the suitability of the demonstrated system to disturbance management when the live demonstration is own use.

CONCLUSION

Major interdependencies exist between electricity networks and mobile networks. The sources of the situation awareness of the DSO consist of internal and external sources. Present methods are focused mainly on DSO's internal situation awareness. There are some situation awareness systems to information exchange in disturbances and some of the DSOs are co-operating with their local mobile network operator to locate the most important base stations. However,

any processed information about the interdependencies of the both networks is not supported. Further, the authorities are using multiple web pages and DMS services to achieve the information about both networks.

In this research, a demonstration of a situation awareness system was developed. This system illustrates the interruptions of electricity and mobile networks on a map. Information about the sites and devices that are dependent on either of these networks e.g. remote controlled switches or elderly residents can be added to map. This information can be utilized to improve the restoration process of the electricity networks or mobile network and to improve the resilience of the society in disturbances.

It was noticed from the analysis of the disturbance case, that the remote controlled switches are highly dependent on the mobile network. In the studied case, some contradiction between the modelled state of the switches and the real state appeared, because the effect on base stations outside the observed area could not be taken into account while modelling the mobile network coverage. Otherwise, the modelled area resembled the real case.

Based on the case it is not possible to make a conclusion how the unreachable switches effected on the restoration process of the electricity network. To make these conclusions, the information of the manually controlled switches would be needed in addition to information how long the manual opening process took.

The demonstrated situation awareness system could help the authorities to plan their actions better, e.g. to evacuate only the residents whose life is dependent on one or both of the networks. In addition, the resilience of the society can be improved by using the demonstration to plan the placement of the backup power.

The DSO and the mobile network operator can utilize the system to improve their restoration process after the situation, e.g. the mobile network operator can improve the backup of the base station which is important to the electricity network. Likewise, the DSO can plan the cabling to ensure the electricity supply to important base stations.

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Improving Disturbance Management with Combined Electricity and Mobile Network Situation Awareness System

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Abstract – This paper presents a new method to improve the disturbance management of electricity networks and mobile networks with a situation awareness system that was developed in this study. The system is based on combining the disturbance information from electricity and mobile networks. Both of the networks provide useful information for disturbance management: electricity outage areas from the electricity network systems and coverage outage areas from the cellular network operators. The outage information from an electricity network is received through the Distribution Management System (DMS) service and combined with customer identification codes to find out whether mobile network base stations lack electricity. This information is combined with operational mobile network coverage areas calculated beforehand with an empirical Okumura-Hata path loss model in order to visualize coverage outage areas. A situation awareness system that combines these parts provides new disturbance management insights and shows the disturbances of both networks with one glance. Thus, the restoration plans for both networks can be sped up and critical areas can be more easily prioritized since a clear visual presentation of the situation is easy to comprehend. Therefore, this new method improves the resilience of society, especially during major disturbances. **Copyright © 2016 Praise Worthy Prize S.r.l. - All rights reserved.**

Keywords: Disturbance Management, Electricity Network, Mobile Network, Situation Awareness System

Nomenclature

A	Frequency-dependent constant
$a(h_{MS})$	City size-dependent function
B	Frequency-dependent constant
C_m	Area correction factor
d_{km}	Distance
f_{MHz}	Frequency
h_{BS}	Effective base station antenna height
h_{MS}	Effective mobile station antenna height
L	Path loss

I. Introduction

Storms such as Valio in 2015, the Tapani storm at Christmas 2011, four storms in the summer of 2010 in Finland and the storms Per 2006 and Gudrun 2005 in Sweden caused widespread and long-lasting disturbances in the supply of electric power. In these storms, some individual customers were without electricity even for several weeks.

In January 2011 and January 2015, the snow load on trees caused widespread disturbances in Finland.

In addition to storms that affect rural areas, e.g., Hurricane Sandy caused widespread disturbances in urban areas in the eastern USA in October 2012.

There were, e.g., floods that caused an outage to Manhattan in New York.

Most of these disturbances caused problems for mobile networks, water supply, residential heating and the conditions of farm animals. In July 2014 and January 2015 in Finland, the disturbances of the electricity network caused notable outage regions for mobile networks. Some areas were left without mobile network coverage for almost a day, which greatly influenced the resilience of society [1]-[10].

A situation where both the electricity and mobile networks have a disturbance at the same time is complex to manage. Nowadays the electricity network has a lot of remote-controlled devices such as switches. Some of these devices use a mobile network to communicate with Supervisory Control and Data Acquisition (SCADA).

Meanwhile, mobile network base stations need electricity to operate. The Finnish Communications Regulatory Authority (FICORA) has determined that base stations in Finland must have backup power batteries or some other form of reserve power to maintain the transmission for at least three hours in the event of a disturbance in the electricity network [11]. However, an electricity disturbance can last longer than the reserve backup power, e.g., if a storm delays the beginning of the repair process for a certain time. In addition to remote-controlled devices, the Distribution System Operator (DSO) relies on mobile networks to contact and follow repair teams and contractors during disturbances.

If both stakeholders receive information from each other's networks, their recovery processes could be executed more efficiently.

In addition to the recovery of both networks, information about disturbances can be crucial to public authorities such as fire and rescue services or municipalities. For example, municipalities are responsible for home care patients with safety phones or emergency buttons. If the electricity or mobile network service is lacking, the safety buttons will not function. The disturbance information from both networks would help fire and rescue services and municipalities to target their activities. [2]-[12]

In this study, a new method was developed to improve the disturbance management of electricity networks and mobile networks with a situation awareness system.

The system improves information exchange between different stakeholders in disturbances. The method was tested with an implemented live demonstration of the system. The system presented here is an extension of an earlier demonstration developed for electricity network disturbances [2]-[5].

The development process of the system that is demonstrated was iterative and is based on workshops and user need interviews organized during this study. In addition, a case study of a disturbance situation of both electricity and mobile networks in Finland, presented in [1], was carried out with a demonstration to test and improve the method.

This paper focuses on one main feature of this system, which combines both electricity and mobile network outages in the same view. This information will help the DSO to focus their restoration planning in order to recover the mobile networks they need for their remote-controlled devices. Meanwhile, it will also help mobile network operators to plan their need for extra deployable reserve power. The demonstration example was constructed on the basis of information from multiple operative networks: four from the electricity networks and one from the mobile network.

These network elements were modeled accurately in the situation awareness system that was developed in order to correspond to the actual infrastructure of a certain area in Finland. The main contribution of this paper is to improve the restoration process in electricity supply disturbances by taking into account the effect of the interdependencies between electricity and mobile networks. Section 2 describes the interdependencies between electricity and mobile networks.

The present sources of situation awareness in major disturbances are discussed in Section 3, and Section 4 presents the new method for information exchange in the event of a disturbance. Section 5 describes the implementation of the situation awareness system.

This implementation is then demonstrated in a case study as presented in Section 6. The benefits of the system are discussed in Section 7, and finally conclusions and discussion of the study are given in Section 8.

II. Interdependencies between Electricity and Mobile Networks

The development of electricity networks towards a smart grid has increased their dependency on mobile networks. In previous studies, it has been noticed that there are significant interdependencies between electricity and mobile networks. In the Tapani 2011 storm in Finland, the mobile network coverage was reduced by 25% as a result of outages and it took four days to restore it almost fully. On the other hand, a wide disruption of the mobile network can affect the electricity network if the public mobile networks are congested. [12]-[17]. In recent years, the restoration process of electricity networks has been improved by increasing the number of remote-controlled switches. The reestablishment time can be improved by several hours with these. However, some of these switches use the Global System for Mobile Communications (GSM) network to communicate. If there is no communication between the remote-controlled switches and substations, a repair team has to be dispatched to close the switches manually and this will slow down the restoration process [18], [19]. In addition, there are communication links between substations and SCADA. Often, the mobile network is utilized for their communication because the price is fair for data transfer with adequate speed. Secondary substations can monitor and control the electricity network remotely. This function is important for power system restoration because it helps to locate faults. [16], [20]. The number of Automatic Meter Reading (AMR) meters in electricity networks has increased. Smart metering devices are utilized for reading and recording signals related to power quality and failure detection. Usually, they utilize mobile networks for communication. The data are typically transmitted either via Short Message Service (SMS) or the circuit-switched non-transparent GSM data service. [21]

Remote-controlled devices are not the only thing in the electricity network restoration process that is dependent on mobile networks. The DSO's work management is heavily dependent on mobile networks in disturbances.

The repair teams move around while restoring the network. They need communication access to communicate with the control center to locate faults and to receive permission to fix them. In addition, the teams need information about their next tasks. Most of the communication with the DSO's operator is handled via mobile phones or tablet computers using the Distribution Management System (DMS) service, which also relies on the mobile network. If cellular network coverage is missing, the contractor remains unaware of how to proceed. In addition, some DSOs utilize a work management system that locates their team with the Global Positioning System (GPS) to help with the task allocation [22]. Some of the above-mentioned communication methods are secured by using services

from two different mobile network operators.

However, in many cases mobile network operators share the same masts. Thus, a power blackout at one mast location results in the unavailability of more than one mobile network operator's service availability in that particular area. In addition, it is expected that, e.g., in Sweden the total energy consumption of mobile networks will increase by 20 percent, from 108 TWh in 2015 to 132 TWh in 2021 [23]. Thus, as the need for electricity in mobile networks continues to increase, it is even more important to improve the recovery process of the electricity supply to these networks in disaster scenarios.

The functionality of mobile networks depends on the availability of electricity networks. When there is a power blackout, the mobile network is not able to provide any coverage without any backup power. However, e.g., in Finland, the mobile networks should still continue to operate, because FICORA has issued a regulation [11] stipulating that mobile network base station sites should have backup power for three hours in the event of a disturbance in the electricity network. This is usually implemented with backup batteries, since, e.g., the availability of renewable energy devices, such as solar panels and wind turbines, is a rare sight at base station sites in Finland, mostly because of their low efficiency rate. Thus, base stations commonly rely on battery backup power during electricity disturbances.

The backhaul connections in mobile networks, i.e., the connections from the mobile operators' core network to the base station sites, are mostly implemented with fiber connections.

These connections also rely on the electricity network in order to function. The devices in the backhaul transmission lines usually have a longer backup power reserve than the base stations, at least from six to twelve hours [11]. The most critical sites are equipped with aggregates to enable operation for longer periods of time, together with ready-made contracts with different companies to deliver more fuel to these sites when needed.

III. Existing Situation Awareness Systems for Major Disturbances

At present, in disturbances, the DSO creates the awareness of the disturbance, mainly on the basis of DMS and SCADA, which show the outage situation of an electricity network. In addition, the DSO utilizes a Work Management System (WMS), which reveals the situation of repairers and resources. In most cases, the DSO decides the fixing order on the basis of the locations of customers with high consumption or the faults that cause the most trouble with electricity supply [2]. The present sources of situation awareness in electricity supply disturbances were compared in a previous study [3].

In this study, the comparison was extended to include the sources of situation awareness in mobile network disturbances. In Finland, most of the DSOs display

information about outages on their web pages, e.g., on transformer-level maps. In addition, some DSOs offer DMS services (Fig. 1) to their contractors and to local fire and rescue services in Finland.

These services give access to the DMS view for the authority during disturbance scenarios. A common factor for all of these systems is that there are only a few bidirectional functions on these systems and they are not usually personalized to different user groups. At present, mobile network operators rarely utilize these systems. [2], [3]. There are some Situation Awareness (SA) systems available for electricity supply disturbances. Some of them are designed for common emergency situations and some especially for disturbances of the electricity supply. In Germany, there are a few situation awareness systems that have been developed for disturbances. One DSO has developed a system which delivers information about outages to the authorities. The system filters the needed information about planned and unplanned outages from the network control system. This information is transmitted to the rescue coordination centers via email. The data from the email can be integrated into the systems of the rescue coordination centers. In addition, municipalities receive information about outages via an SMS which includes the phone number of the DSO. [24]

In Canada, the Multi-Agency Situational Awareness System (MASAS) has been developed for exchanging emergency management incident-relevant information between multiple stakeholders. The system has been designed for exchanging information in non-ordinary situations, e.g., in a flood season.

The system is based on a map where information about weather, earthquakes, fires and electricity outages can be presented. The MASAS can be used for sharing information about disturbances of the electricity supply even though it is not designed specifically for that. [25], [26].

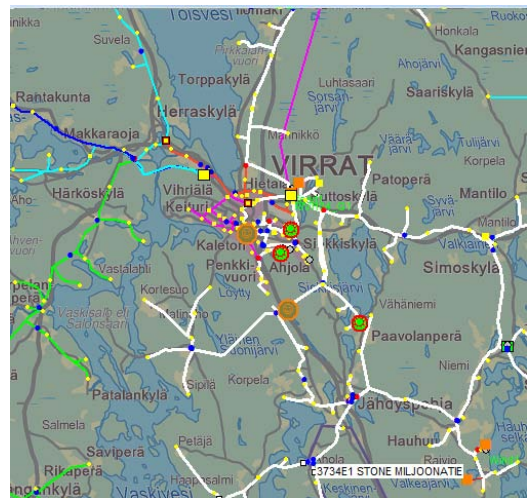


Fig. 1. A view of the DMS service

Generally, the DSO does not know the locations of mobile network base stations. In Finland, some DSOs cooperate with their mobile network operators so that they have information about the location of the most significant base stations.

Nowadays in Finland, different mobile network operators provide their own services for informing subscribers about disturbances of their own network.

There are three main mobile network operators in Finland, which have their own infrastructure, and correspondingly there are three different services for informing the customers. The level of accuracy differs greatly in terms of how precisely, e.g., any disturbance is visualized on a map. FICORA has set minimum requirements for this [27], but even more accurate information can be given. For example, operators can show coverage outages even on a single base station level. In addition, FICORA has a web service which combines the disturbance information of different operators. An example of this kind of disturbance visualization is shown in Fig. 2. The information is usually presented at the municipality level, as can be seen from the figure. However, it is generated only after severe or very severe disruptions to the network and shows only the rough area where the disturbance affects the coverage of the mobile network. One mobile operator in Finland shows the mobile network service problems in considerable detail, together with the expected coverage area of the outage. This is more accurate than is required by FICORA, but illustrates the disturbance situations quite well. In the United Kingdom, e.g., one operator offers a service that can show the coverage areas and some unexpected issues or planned maintenance on a map. However, the problems are shown on the map only after a specific area is searched, and even after an area has been specified, the problems are shown with symbols on the map without a clear influence area.

Thus, only rough estimates of the affected coverage areas are shown. Another operator in the UK has a similar kind of service, but rather than the problem areas being shown on a map, the problems are only listed without specific information on the locations on the map.

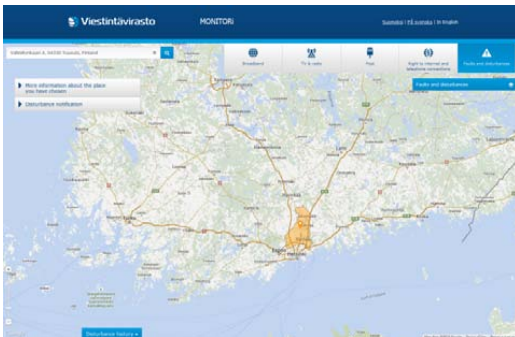


Fig. 2. An example of a disturbance visualization from FICORA's service for severe and very severe disruptions to mobile networks

In Australia, a similar kind of approach is presented as in the UK. In their service, after an address has been defined, a map shows the specific area with the symbols of the base station towers. These symbols also represent whether the service is OK, there is some planned work or there is some live outage at a specific base station site.

Moreover, the map only shows the symbols when an address is defined, and thus the service status map does not show the status of any other regions without a new address being searched for. The mobile network operators receive fault information from the base stations directly to the system. These include, among others, information about any problems related to the functionality of the equipment or warnings about service- or transmission-related misbehavior.

Thus, operators should know whether base station site equipment is not able to access an electricity supply and is forced to utilize the backup power. Additionally, the mobile network operators in Finland have some agreements with the electricity companies to receive information about the status of electricity networks. This helps in following the operational status of electricity networks, but a direct combination of the relations between these networks is not available. Mobile network operators are also prepared for major disturbances. Cooperation with electricity companies is important to coordinate the distribution of backup power to critical areas. However, there is no common system, e.g., a common map service, to show disturbances of both networks that is available for this purpose.

The mobile network operators also follow weather forecasts in order to prepare for possible disaster scenarios caused by storms or other extreme weather phenomena. In Finland, State Security Networks Ltd. has developed a situation awareness system, KRIVAT, that combines information from different stakeholders such as DSOs and telecommunication operators. They offer a map-based view that presents disturbances of electricity networks and mobile networks. However, the system does not present accurate coverage areas of mobile networks. In addition, the service includes a discussion forum for all stakeholders and with meteorology.

The main difference from other existing services is that in addition to a situation awareness system they offer a secured telecommunication connection to their customers. One form of preparedness for major disturbances is a real-life exercise in cooperation with electricity companies and the authorities. Thus, mobile network operators practice in advance the situations in which major disturbances could happen. This improves their ability to react to these events and helps to speed up the recovery process in times of actual disaster scenarios.

IV. The Method for Information Exchange in Disturbances

In this study, a new method was developed to improve information exchange between stakeholders in electricity and mobile network disturbance cases. This method is

based on a concept of a situation awareness system that benefits all stakeholders. [1]-[5].

The method is tested with a developed demonstration of a situation awareness system that specifically combines the information from both the electricity and mobile network.

The demonstration illustrates how the exchange of information between stakeholders could be executed by using the situation awareness system.

IV.1. A Demonstration of a Situation Awareness System

The developed demonstration illustrates disturbances of electricity and mobile networks in a web-based user interface. In addition, it illustrates customers who are heavily dependent on the electricity or mobile network, the so-called critical customers.

The critical customers can be, e.g., patients who need special healthcare, elderly people or critical infrastructure sites such as water pumping stations. Information about critical customers is stored in a manually updated database which users can update by themselves. The structure of the system is presented in Fig. 3. The demonstration combines information from multiple DSOs and mobile network operators as seen from Fig. 3. This information can be combined with information about weather conditions, e.g. lightning strikes, the status of fire and rescue service tasks and traffic report.

The main users (customers) are distribution system operators and mobile operators. In addition, municipalities, authorities and fire and rescue services can benefit from the system. The demonstration can be personalized for different organizations.

IV.2. The User Interface of the Demonstration

The demonstration presents combined information from both electricity and mobile networks on a map.

The user interface of the demonstration consists of a map part to which different information layers can be added and an event log where the amount of the electricity network outages can be seen with one view (Fig. 4).

Fig. 5 shows a closer view of the user interface (the map has been stripped away from the figure because of a non-disclosure agreement). The gray light bulb symbol indicates the transformer station which has an outage and the red polygon indicates the lack of mobile network coverage. In addition, mobile network base stations have their own symbol. The color of the base station symbol shows whether the base station does not have electricity or if it is running on batteries. It is marked with a blue symbol when the situation is normal. If a base station has to rely on batteries, the color of the symbol is yellow, and if it does not have any electricity the color of the symbol is red.

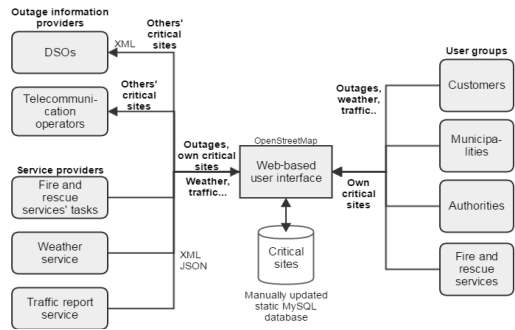


Fig. 3. A diagram of the demonstration

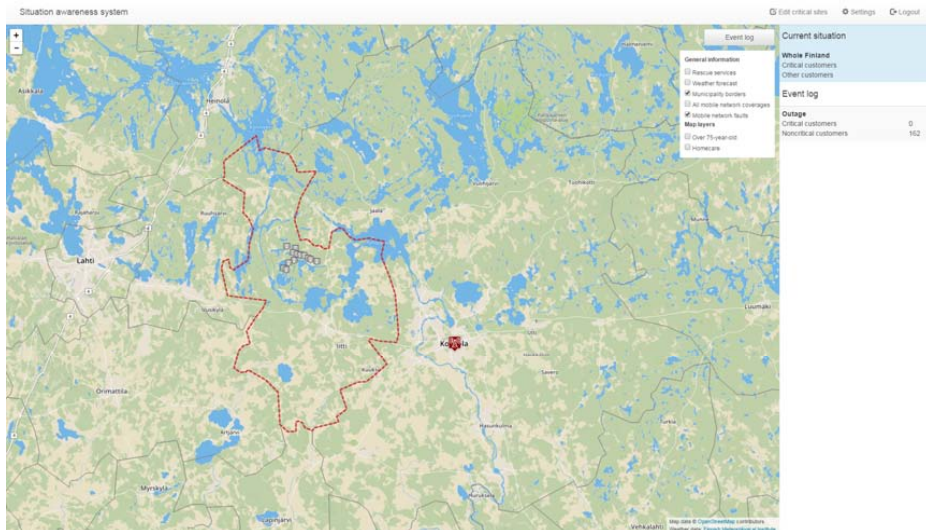


Fig. 4. The user interface of the demonstration

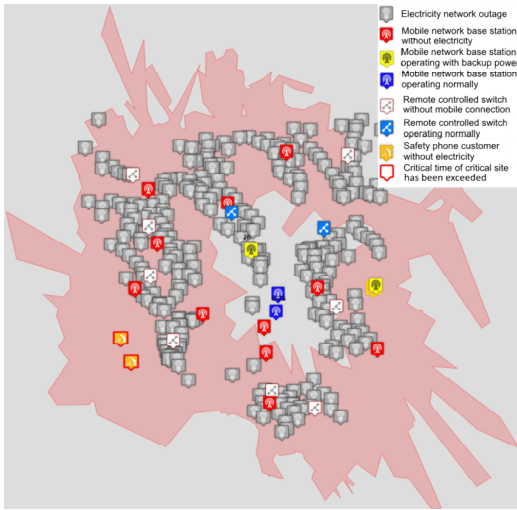


Fig. 5. Detailed view of the user interface during a disturbance

V. The Implementation of the Demonstration

V.1. Electricity Network

The electricity network part of the situation awareness system is based on existing systems and methods used by the DSOs to inform customers about outages and maintenances. The main source of the information is the DMS.

The DMS maintains the distribution network state and signals related systems whenever a change of state occurs. Currently, this method is utilized by the DSOs in order to provide an outage information web page to customers. The web page shows the current state of the network, information on when outages started and the approximate ending time of these outages. This is also used for providing an SMS service in which the DSO informs its users about future maintenance and possible outages as soon as the information about them has been confirmed. When a change of state happens, the DMS generates outage information data about the current state of the network. The data contain important information about the outage, such as the start time, the end time and the type and a description of each outage.

These data are sent to the situation awareness system using the Simple Object Access Protocol (SOAP) or by sending the data as an Extensible Markup Language (XML) formatted file. The data are sent over Hypertext Transfer Protocol Secure (HTTPS). If the data are sent using the SOAP, the DMS implements a SOAP client that connects to the SOAP server implemented by the situation awareness system. The DMS pushes the changes to the situation awareness system whenever a change of state occurs. If a simple file transfer is used, the situation awareness system polls the server changes in the file.

The DMS generates outage information on two different levels; a transformer level and a customer level.

The transformer-level outage information contains the outage information and a list of affected transformers.

The information is generic and cannot be utilized to identify any single customer unless the customer's transformer code is known. The customer-level outage information contains the same outage information as the transformer-level outage information. It also contains more information about the outage, such as a list of affected customers' identification numbers, the certainty of the outage and the state of the outage, meaning whether it is a new outage or recurring outage or the supply is temporarily restored. These data can be used to identify a single customer.

Once the data are received, the system saves the data into a relational database (such as MySQL or PostgreSQL). As the data are sent on two different levels (the transformer and the customer level) the data are first parsed and combined together. Each outage has a unique identifier that can be used to combine the two levels of outage information together.

Users connect to the system with a web-based user interface. The user interface works on all modern browsers. Once a user connects to the system the user requests data from it. The outage information which the user is interested in is sent to the user on the basis of previously set organizational information and user settings.

The data that are received are further parsed on the user's browser and displayed to the user. The data can be further filtered by the user in the browser-based user interface. The user interface keeps on polling the server for changes in the network in order to keep the user interface up to date.

V.2. Mobile Network

The implementation of the mobile network part of the system was based on the existing infrastructure of a mobile network operator and accurate configuration data available for a certain area in Finland. The individual coverage areas were accurately simulated with a mobile network simulation tool in which all the necessary configuration parameters had been taken into account.

These included base station locations, antenna heights, antenna directions, antenna tilting levels, antenna models and their gains, transmission powers and any additional losses, as well as the frequencies used for GSM and the Universal Mobile Telecommunications System (UMTS), i.e., the second-generation (2G) and the third-generation (3G) cellular networks.

In addition, the simulations required information about the elevation data of the area in the form of Digital Elevation Maps (DEMs), together with the type of environment the area had. The environment is taken into account with different morphographic corrections, which cause different attenuations for the propagating signal.

The simulations then used the Okumura-Hata [28] path loss model to calculate the final coverage areas for every GSM and UMTS cell. This is based on calculating the maximum distance that the signal between the base station antennas and the user equipment can propagate.

The Okumura-Hata path loss model or its extension, the COST-231-Hata model (for higher frequencies), is defined as:

$$L = A + B \cdot \log_{10}(f_{\text{MHz}}) - 13.82 \cdot \log_{10}(h_{\text{BS}}) + a(h_{\text{MS}}) + (44.9 - 6.55 \cdot \log_{10}(h_{\text{BS}})) \cdot \log_{10}(d_{\text{km}}) + C_m \quad (1)$$

where:

L is the path loss in [dB],

A, B are frequency-dependent constants,

f_{MHz} is the frequency used in [MHz],

h_{BS} is the effective base station antenna height in [m],

h_{MS} is the mobile station antenna height in [m],

$a(h_{\text{MS}})$ is a city size-dependent function,

d_{km} is the distance between the base station and mobile station in [km], and;

C_m is an area correction factor.

The constants A and B are defined separately for different frequencies according to Table I [28].

The city size-dependent function $a(h_{\text{MS}})$ is defined as:

$$a(h_{\text{MS}}) = 3.2 \cdot (\log_{10}(11.75 \cdot h_{\text{MS}}))^2 - 4.97 \quad (2)$$

$$a(h_{\text{MS}}) = (1.1 \cdot \log_{10}(f_{\text{MHz}}) - 0.7) \cdot h_{\text{MS}} + (1.56 \cdot \log_{10}(f_{\text{MHz}}) - 0.8) \cdot h_{\text{MS}} \quad (3)$$

Eq. (2) is defined for large-sized cities with frequencies greater than or equal to 300 MHz and (3) for small to medium-sized cities for all the valid frequencies presented in Table I. The area correction factor, C_m , is also defined separately for different-sized cities.

For large-sized cities C_m is 3 dB and for medium-sized cities it is 0 dB [28]. It should be noted that there are some limitations on how to use the COST-231-Hata propagation model.

The model is valid for frequencies between 150 and 1000 MHz and 1500 and 2000 MHz for ranges between 1 km and 20 km. In addition, the effective base station antenna height is limited to between 30 and 200 meters, while the mobile station antenna height is limited to between 1 and 10 meters.

Nevertheless, all of the values used in the simulations for the simulated area are within the limitations.

TABLE I
COST-231-HATA PROPAGATION MODEL CONSTANTS

	150-1500 MHz	1500-2000 MHz
A	69.55	46.3
B	26.15	33.9

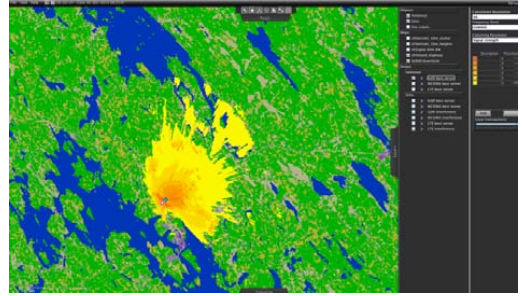


Fig. 6. An example of the coverage simulation for one cell

Another aspect that defines the behaviour of the Okumura-Hata model is the propagation slope, which is the $(44.9 - 6.55 \cdot \log_{10}(h_{\text{BS}}))$ part in (1).

As can be seen, the only variable in defining the propagation slope is the effective base station antenna height, h_{BS} . However, the propagation slope defines the way the signal attenuates while propagating through the environment. Thus, with a fixed h_{BS} , the only way to change it is to change either the value 44.9 or the multiplier 6.55. The simulation tool fine-tunes the value 44.9 with respect to the environment to get the correct propagation slope for the correct areas.

The simulation results are exported separately for each base station site as images in order to visualize the cell coverage areas. An example of the coverage simulation for one cell is shown in Fig. 6. It should be noted that the coverage area follows the differences in elevation and the effect of different types of environments.

On the basis of the customer identification code or the transformer code, the base stations can be combined with the outage information. The result of the connection is utilized to find out whether the base station does not have an electricity supply from the network.

Other fault information can also be imported into the situation awareness system. Besides the fault information about the lack of a power supply from the electricity network, the information about the status of cells is also imported into the system. This enables the system to visualize the lack of coverage, e.g., in the case of maintenance work.

V.3. Other Information

Other information is needed for the system to be operational. Critically electricity-dependent site information is important to the system. The data are received from the users of the system and can be imported into the system in two ways. Users can utilize the web-based user interface to add new sites manually.

This is viable in cases where the number of sites is low, as in the case of a small water utility. In cases where the stakeholder has a high number of critical sites (such as a municipality), integrating the stakeholder's database is also possible.

The critical site database is then automatically updated once a site is added to the stakeholder's own database.

The weather information in the system is fetched from an interface provided by the Finnish Meteorology Institute (FMI). FMI provides a Web Feature Service (WFS) compatible interface for fetching the weather information. FMI provides forecasts, current weather information and history information. The data are fetched using Hypertext Transfer Protocol (HTTP).

The Finnish rescue services provide an interface for media and other users to get information about the current activities of the rescue services. These data are also fetched from the interface using HTTP.

Furthermore, other information can be implemented into the system; e.g., the Finnish Transport Agency (FTA) provides information about the current traffic situation. These data can be fetched from the SOAP interface provided by FTA. In addition, the system can be integrated with DSOs' work management systems to follow the location of the repair teams.

VI. The Live Demonstration – Case in Finland

The demonstration was tested in two different cases. In the previous study the system was tested on the basis of history data from a disturbance case in Finland that affected both the electricity and mobile networks [1].

In this study, the system was tested with live operational networks.

A live version of the demonstration was developed to test how the SA system could be implemented.

The demonstration combines information from four DSOs and one mobile network operator. The demonstration presents the lack of coverage areas in the mobile network and outages of the electricity networks on the transformer level on a map view. The area that is studied is the operating area of the chosen DSOs.

In addition to mobile network coverage, the base stations that have faults are also shown on the map.

The information on the outages is combined with the information about the location of the critical customers.

Customers can be added to the system on the basis of their transformer number. The system gives a warning when a critical customer has an electricity network outage. In order to implement this functionality in (near) real time, an interface between the mobile network system and the situation awareness system was developed.

In the system, the mobile network fault information is collected every 10 minutes from a file that has been generated by the mobile network operator and sent to the situation awareness system. The system then extracts the information and visualizes the possible changes that have happened after the previous fault information update. This enables a near real-time presentation which is still relatively light to compute.

The data from the DSOs is collected every five minutes from the DSOs' web page interface.

At present, the outages of the electricity networks are observed on the transformer level.

The live demonstration was tested for two months in this study. The disturbances that occurred during the testing time were observed with it. During the testing period there were no major disturbances to any of the networks. Smaller outages occurred once or twice per week. Once a small electricity network outage resulted in just one mobile network base station blackout (Fig. 7).

In this case the outage did not have an effect on mobile network coverage because the other base stations nearby covered the missing area.

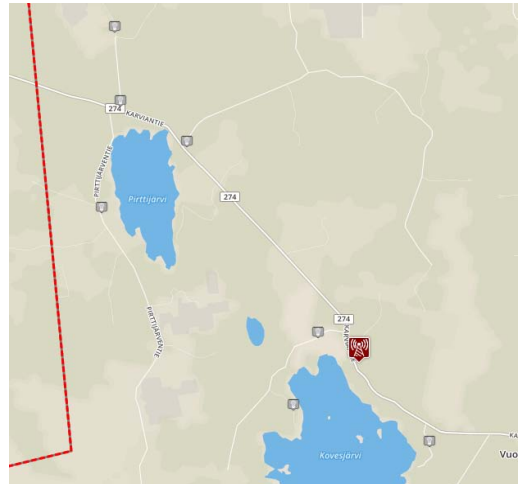


Fig. 7. Outage of electricity network and faulted base station of mobile network illustrated in the demonstration

VII. Benefits of the Method for Situation Awareness System

The combined electricity and mobile network situation awareness system helps to monitor the electricity and mobile networks, especially in the event of major disturbances. It improves the restoration process as a result of the added value from the interoperability of these networks.

In addition, the resilience of the society during disturbance situations improves when the authorities have information as to whether their critical customers or critical sites lack electricity or mobile service.

This information can then be utilized to prioritize the restoration process of the networks for the most critical areas. Thus, repair teams are able to concentrate more on the most critical areas, and if the situation changes it will be visible in the system and changes to the repair order can be decided fluently and effectively. The improvements in terms of information exchange and benefits to the system are illustrated in Table II.

As shown in the case study [1], the situation awareness system can be utilized to find out the vulnerabilities and the interdependencies of critical infrastructures.

This information can be highly useful when planning an electricity or mobile network. In addition, the information can be utilized in a restoration planning process. Illustrated situation awareness improvements help DSOs to plan their restoration processes more effectively.

The repair order of the electricity network faults can be changed so that the most important base stations utilized by DSOs' remote-controlled devices are restored first. In addition, the fault repair order can take into account the most disturbance-vulnerable electricity consumer sites, which are important to the resilience of society. This can also improve DSOs' network planning by recognizing existing problematic areas, which could be prevented in the planning process of new areas.

If the DSOs know the location of the important base stations, they can plan the network so that those areas are more resilient, e.g., with ground cabling. Furthermore, the DSOs can consider changing the communication media in those areas where mobile network coverage is

most vulnerable to disturbances. One benefit of the system is that the DSOs and the mobile network operators can find out how their recovery process is working. They can detect if everything went as planned. Likewise, they can find out whether the processes of the other stakeholders caused the problems or if the problems were in their own processes.

In addition, the demonstration can extend the DSOs' work management with the information about repair teams which do not have mobile network coverage.

It can also be utilized to warn the teams before they move to an area without coverage or to inform them beforehand where to proceed when they need to find some coverage. With the information received from the demonstration, mobile network operators could plan their backup power batteries or reserve power more precisely. They can recognize the base stations that are the most important to the resilience of the electricity network and improve their backups.

TABLE II
SITUATION AWARENESS BENEFITS

	Present	With situation awareness system	Benefits of the system
DSOs	customers with high consumption of electricity	customers who are heavily dependent on electricity	DSOs can take these sites into account when planning the network or the restoration plan
	no or some important base stations of mobile network	all faulted base stations of mobile network	base stations most important to DSOs' operation can be detected and secured
	inaccurate awareness of mobile network coverage	detailed awareness of mobile network coverage	predict the possible disturbances in own network caused by mobile network
	location of repair teams	information if repair team does not have mobile network service	repair team can be informed beforehand where to proceed when they need to find some coverage
	location of remote-controlled devices	warning if remote-controlled device does not have mobile network coverage	prediction if this can affect DSOs' own restoration process
	warning if base station does not have electricity supply from the electricity network	estimation of the end time of the outage	prediction if more backup power is needed
	inaccurate information about the running time of the backup power of the base stations	prediction of how long the mobile network will operate with backup power after the first outage	mobile network operators can utilize this information to renew poorly functional batteries
Mobile network operators	inaccurate awareness of disturbances of electricity supply	detailed awareness of disturbances of electricity supply	predict the possibility of disturbance situation in own network
	base stations that are the most important for mobile network coverage	base stations that would be most important to the restoration of the electricity network	mobile network operators can improve their backup for the most important base stations to expedite the coverage restoration process of the mobile networks
	no information about critical customers that are highly dependent on mobile coverage, e.g., home care patients, retirement homes	which base stations are most important to the critical customers, e.g., retirement homes	the sites can be taken into account when placing the backup power
Authorities & Municipalities	inaccurate awareness of disturbances of electricity network	detailed awareness of disturbances of electricity supply from one view	authorities and municipalities can improve the planning of their own duties
	inaccurate awareness of mobile network coverage	detailed awareness of mobile network coverage	authorities and municipalities can improve the planning of their own duties
	location of customer whose life is dependent on electricity supply or mobile network coverage	warning if critical customer does not have electricity supply or mobile network coverage	prediction of whether residents need to be evacuated or otherwise helped
	location of own critical sites, e.g., water pumping stations	warning if critical site does not have electricity supply or mobile network coverage	municipalities can plan which sites need backup and which can be substituted, e.g., sharing water among residents instead of providing the backup to a water pumping station

This can expedite the coverage restoration process of the mobile networks. Further, the information about disturbance areas of electricity networks can be used to find the most vulnerable base stations from the operators' own network and increase their backup power batteries or other reserve power. While cooperating in the network planning process, DSOs and mobile network operators can detect the most vulnerable areas for the operations of both networks and plan the backup power together.

In the long run, the SA system makes it possible to detect deteriorated mobile network base station backup batteries. The DSOs can use this information to, e.g., plan their restoration process so that the electricity will be restored first at those locations. The mobile network operators can utilize this information to renew poorly functional batteries.

The information feed to the system can be processed further; e.g., when the customer number of the base station is known, it is possible to detect if it does not have electricity feed from the network at the moment. Further, knowing that the base station is still working means it is possible to find out that it is working on batteries. In this case, how long the batteries will work can be determined.

The information can then be saved into the system for later utilization. DSOs can utilize this information to predict how long their devices will have a mobile connection. In addition, the mobile network operators can utilize this information in the maintenance planning process.

Besides improving the recovery of the electricity and mobile networks, the system can improve the resilience of society in disturbances. Municipalities are able to recognize the customers who have safety phones or safety buttons in areas which are temporarily lacking mobile network coverage or an electricity supply. Municipalities can utilize the information to send help to customers or to plan their evacuation. The warnings of critical sites help municipalities to plan the placement of movable reserve power or to plan whether the site can be substituted, e.g., sharing water among residents instead of providing backup power to a water pumping station.

For authorities such as the fire and rescue services the awareness of the disturbance area plays an essential role for their operation. Thus, they can prepare for an increasing amount of work and summon more officers to duty. The combination of the information of multiple DSOs reduces the number of information sources and the workload of the authorities. With the situation awareness system, the fire and rescue services can increase their help to the municipalities, e.g., it will improve evacuation planning together with municipalities.

VIII. Conclusion

In this study, a new method to improve the disturbance management of electricity and mobile networks was presented. The method is based on a situation awareness system which combines the

information from both the electricity and the mobile network. During the study a demonstration of the system was implemented utilizing the existing systems. To test the method a live demonstration was performed in Finland.

The demonstration combines information from multiple DSOs and one mobile network operator.

The main problem with the present situation awareness systems utilized in disturbances of electricity and mobile networks is that the interdependencies of different infrastructures are not taken into account and the information presented in the system is not further processed as is the case in the MASAS system [25], [26].

In addition, some of the systems are still limited to presenting information from only one stakeholder.

This can hamper the restoration process of the networks. The authorities and the operators of both networks can benefit from the situation awareness system and not only the authorities as in the system presented in [24]. The DSOs and network operators can utilize the system in restoration planning, e.g., the mobile network operators can place more backup power at the base stations that are most important for the operation of the electricity network. In addition, the information from the system can be utilized to improve the network planning, e.g., DSOs can ensure the electricity supply for the most important mobile network base stations by ground cabling. For the authorities the most beneficial functionality is the information about the status of the critical sites. With this information they can focus their actions on the right residents, e.g., safety phone customers. There can be problems in adopting the new method if it depends on a commercial system, where the data are produced by customers themselves. Some of the existing systems have had problems acquiring customers because the variety of the input data is dependent on the number of customers that produce the data.

In that case, the amount of information received for first users is limited and the benefits of the system stay low. The best situation in which to adopt the method is if there is legislation or regulation that forces the stakeholders to add data to the system. In that case, the system could utilize all the data at the same time.

IX. Further Studies

The future research should relate to analyzing the performance of the real-time system and its impact on the overall time needed to manage disturbance situations.

The testing of the live demonstration will continue further. The main goal is to test the demonstration in the event of a major disturbance that affects multiple electricity networks and mobile networks. In addition, more users will be added to the system, e.g., DSOs and municipalities, for testing purposes. The future research around this new method should also include developing additional algorithms, e.g., automatic warnings on top of the system that has been developed. In addition, e.g., machine learning algorithms could highlight interesting

information from the operational networks, especially about the interdependencies between the networks.

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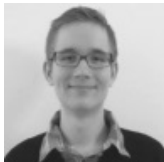


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Improving resilience of society in major disturbances of electricity supply

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Abstract

Purpose – The purpose of this paper is to introduce a method of improving the resilience of the society in major disturbances of electricity networks by situation awareness system that combines information about disturbances of electricity networks, mobile networks and sites that are highly dependent on electricity. A demonstration of the situation awareness system was developed to test the method.

Methodology –The problems with present methods for information exchange in major disturbance were studied by semi structured interviews. Additionally, the requirements for situation awareness were asked in interviews and workshops. A demonstration of a situation awareness system was developed with active design research method. Further, the demonstration was evaluated by presenting it in cooperative workshops with different organizations and in interviews.

Findings – In this study, it was noticed that the information required in the disturbance varies based on the organization. Present systems do not take account this variation. Common for authorities was that they need information from multiple sources to the same view. The situation awareness system can change the restoration process of the electricity network so that the sites that are highly dependent on electricity can be taken account more efficiently. Additionally, authorities can plan their processes more efficiently when they know the locations of these sites. The developed system can decrease the workload of the users in disturbances by decreasing the amount of views needed to achieve the situation awareness.

Originality – This study underlines the need for improved communication in major disturbances of the electricity network. The developed demonstration differs from existing systems, because it includes a criticality database, which stores information about sites or customers that are highly dependent on electricity supply. This method changes the restoration process of the electricity network in a way, that the resilience of the society is improved by taking account the most vulnerable sites of the society.

Keywords Electricity networks, Major disturbances, Resilience of society, Restoration process, Situation Awareness System

Paper type – Research paper

1. Introduction

There have been several problems in the information exchange between stakeholders in major disturbances of electricity networks. Usually in disturbances, municipalities and authorities receive information by the distribution system operators' (DSOs') web pages, like transformer level maps or lists that show the outages and their duration and phone conversations. Information is shattered to multiple sources and some stakeholders do not have any information exchange between each

other. The biggest problems have been in lack of interoperability between rescue services, DSOs and mobile network operators (MNOs). Similar problems have been worldwide, e.g. in Sweden, in Germany and North America. In Finland, one municipality had problems to reach the local DSO during a disturbance in 2011. They had only the phone number of the DSO's customer service, which was congested. (Krohns-Välimäki et al. 2016, Strandén et al. 2014)

There have been several storms like Rauli in 2016, snow storm at Juupajoki in 2015 etc. in Finland and Per in 2006 and Gudrun in 2005 in Sweden, that caused widespread and long lasting disturbances in the supply of electric power. In those storms, some individual customers were without electricity for a few days. In January of 2018, 2015 and 2011, snow load on trees caused widespread disturbances in Finland. In addition to storms that affect the rural area, the Hurricane Sandy caused widespread disturbances in eastern USA in October 2012 including some cities. There were e.g. floods that caused outage to Manhattan in New York. Typically, these disturbances caused problems in telecommunication, water supply, residential heating and animals' conditions in farms. (Krohns-Välimäki et al. 2016, Strandén et al. 2014, Energy Market Authority 2011, UCTE 2007, U.S.-Canada Power System Outage Task Force 2004)

The legislation and standard compensations are guiding the present restoration process of the electricity networks to minimize the amount of the disturbances and to minimize their duration. Thus, the restoration process of the electricity networks is usually planned based on the customers with high consumption or the faults that cause the most trouble with electricity supply. In Finland, DSOs are obligated to pay stepwise increasing compensations so called standard compensations to customer when an outage is lasting 12 hours or longer. (Electricity Market Act 2013)

In the field of electricity distribution, studies usually focus on finding the ways to avoid disturbances or to recover the network quickly. However, achieving high-level reliability can easily come expensive. This paper presents a method to take the resilience of society into account in restoration process of electricity network. To accomplish this, it is important to enhance the preparing for disturbances and to increase information exchange between different organizations. Likewise, this can improve the planning of the recovery process of the electricity network.

The paper presents the interdependencies between critical infrastructures and electricity supply. Furthermore, requirements of information exchange between stakeholders in disturbances of the electricity networks have been analyzed. A demonstration of situation awareness system based on these requirements is presented. It consists of an internet service, which combines information about disturbances of the electricity supply, disturbances of the mobile networks and information about sites that are highly dependent on electricity. Further, the paper presents the effects that system has for the resilience of the society and how this can change the restoration process of the DSO.

2. Methods

In this study, cooperative workshops with different organizations and semi-structured user need interviews to one municipality and two fire and rescue services were done to find out their requirements for situation awareness in disturbances. Additionally, the interdependencies of the stakeholders were studied. These methods supplement different phases of the development process.

The participants of the cooperative workshops were representatives from different units of one municipality, e.g. the manager of social security and field leader of the home care. Additionally,

there were representative of fire and rescue service, voluntary rescue service (VAPEPA “Vapaaehtoispalvelu” in Finnish) and DSOs.

In the interviews, the present methods achieving the situation awareness were studied. Further, it was solved what information interviewees required to carry out their processes. The interview was semi-structured i.e. questions were planned in advance, but some of them were changed during the interview based on the previous answers. (Bernard et al. 2006)

Action Design Research (Sein et al. 2011) was used to develop a demonstration of the situation awareness system. The method addresses with two challenges: 1. intervening and evaluating a problem situation that encounters in a specific organizational setting; and 2. developing an IT artifact that addresses the problems typified the encountered situation. The development process includes the influence of users and ongoing use in context. Versions of the system were presented to end-users in the design process.

3. Interdependencies of the critical infrastructures and electricity network

An interdependency can be defined as a bidirectional relationship between at least two infrastructures, i.e. the state of each infrastructure influences the state of the other (Rinaldi et al. 2001). A major disruption in one infrastructure can cause a failure of another infrastructure. Thus, the disruptions can spread wide. There are multiple studies about the effects of the interdependencies of the critical infrastructures in emergency or disruption management. (Baloye et al. 2017, Rääkkönen et al. 2017)

The interdependencies between electricity networks and other critical infrastructures like mobile networks effects on the restoration process of the electricity networks. In 1997, the U.S. President's Commission on Critical Infrastructure Protection defined eight critical infrastructures; telecommunications, electric power systems, natural gas and oil, banking and finance, transportation, water supply systems, government services, and emergency services. (Rinaldi et al. 2001, Zimmerman 200, U.S. President's Commission on Critical Infrastructure Protection 1997)

Based on the workshops of this study, the most of the critical infrastructures are dependent on electricity supply. Water supply is mostly dependent on electricity supply because water pumping needs electrical pumps. In major disturbances of electricity networks, water towers can be used to supply water for nearby areas as long as they have water because the process is based on pressure. In some cases, the most critical water pumping stations have been secured with backup power or with option to connect removable back up power. (Landstedt et al. 2007)

In Lewis (2006) definition, the public health is one of the critical infrastructures. The public health can be divided into different parts based on who is responsible for it and if the service is centralized, like hospitals or distributed like home care patients. Usually, the hospitals are secured for electricity supply disturbances e.g. hospitals can have doubled connection to the electricity distribution network and the most critical functions of the hospitals like operating theaters are secured with own backup power.

As a part of public health, there are some home care patients that are highly dependent on electricity e.g. patients with a medical ventilator or with a home dialysis machine. Mostly these machines are secured with back up batteries that are usually planned for few hours only. In longer electricity supply disturbances, these patients require help. In Finland, the special health care is responsible for these patients. In the workshops of this study, it relieved that some municipalities have opportunity to evacuate the home care patients if necessary. However, they do not have

enough resources to evacuate all the elderly citizens who may require assistance in disturbance situation.

Fuel supply has many interdependencies with electricity network. Fuel pumping is highly dependent on the electricity supply while the restoration process of the electricity network is dependent on the fuel supply for the repair groups. Additionally, the public authorities like fire and rescue services needs fuel supply to maintain their processes. Some fire and rescue services have a contract with their local fuel pumping stations that they deliver the backup power there.

Most of the grocery shops cannot function in electricity supply disturbance, because they cannot handle money transactions without electricity. Thus, the food supply is critically dependent on electricity. Some bigger shops have possibility to receive cash. However, most of them do not have backup power for their freezers, so the food will go off fast. Some municipalities have contracts with the local grocery shops to receive food from them to deliver it to citizens.

Schools and childcare are vulnerable to disturbances of electricity networks because they do not usually have backup power. In case of the major disturbances, municipalities should offer a safe place to children to spend their day and their parents might be bound to processes to secure the resilience of the society.

Electricity networks and mobile networks have many interdependencies between each other. The development of electricity networks has increased their dependency on mobile networks by adding distribution automation that needs mobile network to function. Additionally, the functionality of mobile networks depends highly on the availability of electricity networks; to provide any coverage the mobile networks needs the electricity supply. (Clark et al. 2010, Horsmanheimo et al. 2013, Kjolle et al. 2012, Salomäki 2013, Rigole et al. 2006, Rinaldi et al. 2001).

Moreover, the resilience of the society is dependent on mobile networks. In Finland, the authorities have their own telecommunication network that is secured for disturbance situations. However, some of these masts have backup power only for six hours. Thus, some fire and rescue services use satellite phones to secure the communication. Additionally, some municipalities and fire and rescue services uses landline telephones in electricity supply disturbances. In addition to their own processes, municipalities are responsible for some elderly customers who use safety phones. In a disturbance situation, safety phones may stop operating if they do not have mobile network coverage or if their batteries run out.

4. Situation Awareness in Disturbances

A. Present methods for information exchange

Based on Endsley's (1995) definition, the situation awareness can be seen as the triad of "perception", "comprehension" and "projection". Formation of the situation awareness is an iterative process. (Endsley 1995)

At present, DSOs use mainly Distribution Management System (DMS) and Supervisory Control and Data Acquisition (SCADA) to form the situation awareness in disturbances. These systems focuses on the DSOs' own network. Sometimes work management systems are used to receive information about resources. (Northcote-Green et al. 2006, Kuru 2009)

There are some situation awareness systems developed for disturbances of electricity supply. Most of them are used for information exchange between one DSO and few authorities. Additionally, some systems that are designed for emergencies can be used for major disturbances

electricity supply. (Ley et al. 2014, Schweer et al. 2013, Pagotto et al. 2012, State Security Networks 2018, Tieto 2017, Kupila et al 2017, Elsamverkan portalen 2018)

The information that other organizations receive from disturbance comes mainly from phone conversations or from DSOs' public web pages, which shows outages on transformer level on maps and lists of outages. Additionally, some DSOs offer a Short Message Service (SMS) service that sends the outage start time, estimated duration and the estimated end time information to the customer. (Kuru 2009, Elenia 2018)

Authorities and municipalities are using several information sources to create the situation awareness. Based on the workshops of this study, the fire and rescue service is using the public web pages of the local DSOs to achieve information about disturbances. In addition, the fire and rescue service follows weather forecasts and warnings that are meant to authorities from weather service. (Horsmanheimo et al. 2017)

In Finland, nowadays some fire and rescue services have a specific display that provides them the same information that is in the DSO's DMS so called DMS service. They are used to locate the outage and to find out the estimate duration of it. Additionally, in some cases, a representative from fire and rescue services has been following the disturbances in the DSO's operating room as a contact person.

Furthermore, fire and rescue service is using their own systems to follow their own tasks and units and weather service to follow the weather warnings. They deliver information further for municipalities and media. Mainly e-mails, phone calls, Short Message Service (SMS) messages and government official communication network (in Finland called VIRVE "Viranomaisverkko"). Sometimes, fire and rescue service shares print screen from the DMS service of the outage area to municipality.

Usually, municipalities form the awareness in disturbance situations by combining information from multiple databases, maps and DSOs' public web pages. The DSOs' public web pages are used to receive information about the location, the scale and estimated the duration of disturbances. Additionally, some municipalities receive information about disturbance by Short Message Service (SMS) messages from the local fire and rescue service. Further, some municipalities do not have any direct method to exchange information with DSOs.

Based on the workshops, the most vulnerable customers of municipalities are elderly people living alone, disabled people and people with mental health issues. The home care uses DSOs' web pages and compares with addresses from their own customer database to find out if there are customers without the electricity. Elderly people who do not use home care can be located with resident database.

B. Problems with present methods

An example of the complexity of the present ways of information exchange in disturbances is presented in Fig. 1. It has been simplified to illustrate the information exchange between one representatives of the main stakeholders related to disturbance situation. However, there are multiple similar connections in the real case, because there can be multiple DSOs in the operating area of the authorities. The main problems with present methods are that there is no information exchange between all stakeholders while most of the methods includes only two stakeholders. Thus, none of the methods gives awareness of the whole situation.

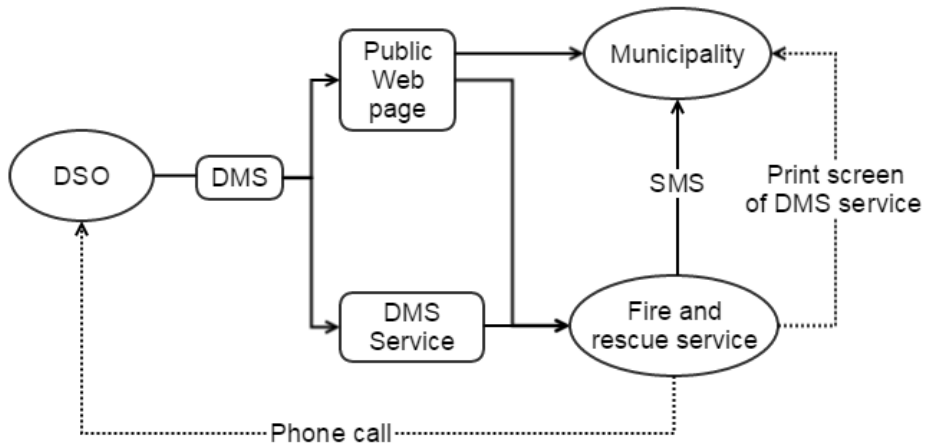


Fig. 1 Present ways to exchange information in disturbances.

Based on the interviews, some of the stakeholders had problems with the present methods. One fire and rescue service told that they used DMS service only rarely because it was complex to use. Furthermore, the other fire and rescue service used the same service often, even in small disturbances. One of the main problems with the DMS service and the public web pages of the DSOs is that they present information only from one distribution network. Most of the fire and rescue services have many DSOs operating in their operation area, so they need a different system for every DSOs in widespread disturbances. Another problem is that the DMS service is originally meant for electricity network operators not for fire and rescue service operators. Thus, the system is complex to use, and has professional terminology which is hard to understand.

The workshops revealed that some DSOs have information about customers and sites that are highly dependent on electricity e.g. nursing homes. However, this information is updated only if the customer or site will contact the DSO to change the information, so most of this information is outdated and unreliable.

The interviews and workshops of this study relieved that the municipalities have had multiple problems in information exchange with DSOs. In one case, local DSO did not have information about the location of a nursing home, they thought it was a regular customer and did not consider it in the restoring process. Furthermore, municipalities are still relying on the hardcopies of their customer information and using paper maps to locate customers who need help. In the workshops, it relieved that the information about elderly people and home care patients locations is shattered. There are multiple maps and databases and the information is spread between them. Additionally, the information from the DSOs' is often inaccurate e.g. outages are usually shown at transformer level, while municipalities and fire and rescue services would need exact information about people who are without electricity.

C. Users' requirements for situation awareness system

One part of the interviews concerned about the information that stakeholders requires in major disturbances. The same questions were discussed in the workshops of this study. The main result is that the information required varies depending on the organization. The main requirements of

stakeholders are following:

- DSOs requires following information:
 - Where the outage is located?
 - What causes the outage?
 - How the electricity can be restored?
 - Is there mobile network coverage in the area?
 - How the actions of the other organizations affects to the restoration process?
 - What kind of weather there will be?
 - How long base stations of the mobile network can handle without the electricity?
 - Is customer or stakeholder using a backup power?
 - Where evacuation is planned to carry out?
- Fire and rescue services requires following information:
 - Is there disturbance in their operation area?
 - Which DSO is operating in specific location?
 - Are there people in danger?
 - Does municipality plan to evacuate?
 - What kind of weather there will be?
- Municipalities requires following information:
 - Are there home care patients or elderly people in disturbance area?
 - Is there a disturbance in their operation area or in neighbor municipalities?
 - Are there people who need help in getting food, water or shelter?
 - Are there patients with safety phones or buttons that do not have electricity or mobile coverage?
 - What kind of weather there will be?

Further, the use cases for a situation awareness system were asked in the interviews and workshops. Based on the interviews stakeholders need bi-directional functions for systems. At present systems, fire and rescue services are not able to send any information back to DSOs. They would need a system where they could mark the fault places, which they have seen, and send the information to DSOs. Additionally, common for all interviewees is that they want a functionality that would enable to share the information to other organizations like home care employees of municipality and voluntary organizations by email or SMS.

According to the interview, municipalities would benefit highly on a system that shows the overall situation and citizens who are highly dependent on electricity supply or mobile network coverage e.g. special health care patients or elderly people with safety phones or buttons. They

want to see their customers on a map instead of the present registers. It would help them to have a perception of the scale of the situation.

Further, a need for a combination of information about mobile and electricity network disturbances emerged. The information about mobile networks is important for DSOs because they have devices, which are dependent on a mobile network like remote controlled switches, in their network. Additionally, the authorities can use information about mobile networks to locate people whose emergency buttons or phones may not work.

5. Demonstration of combined situation awareness system

A. The Concept of the Situation Awareness System

A concept of the situation awareness system illustrates how information exchange between stakeholders could be executed in major disturbances (Fig. 2). One challenge with the currently used methods is that organizations have to use multiple systems to create situation awareness during the outages. The main difference between the present methods is that the concept combines information from multiple DSOs and it filters the information to operation area of the user. Additionally, there is a critical sites database, which includes information about highly electricity dependent sites. The concept is developed to make improvements to problems that occurred in the interviews and workshops.

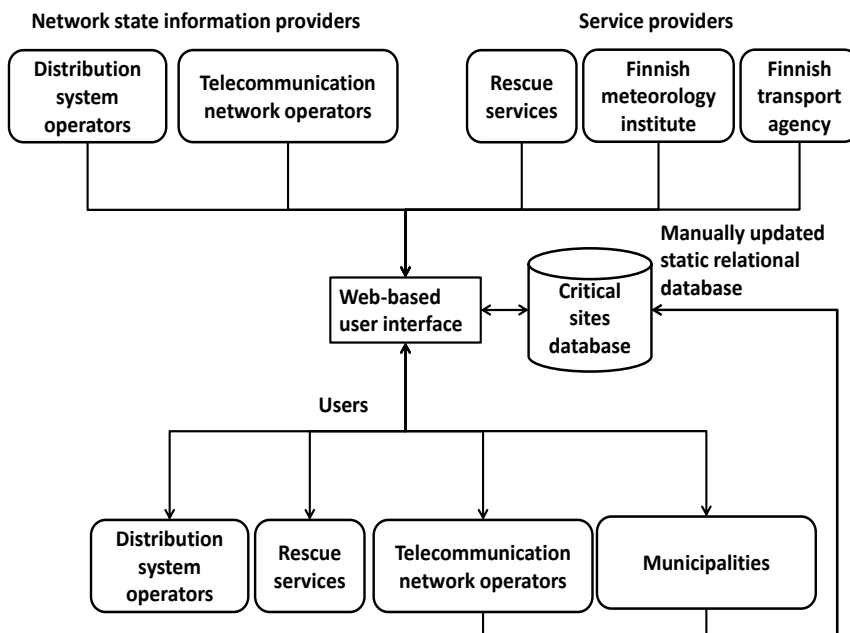


Fig. 2. The structure of the situation awareness system

In this concept, the users of the system have been divided into different user groups depending on the information they need and the information they are allowed to access. The user groups are

DSOs, MNOs, authorities, municipalities and critical customers, who have the sites that are critically dependent of electricity. The information inputted to the system can be e.g. outages of the DSOs, disruptions of the mobile network, tasks of the fire and rescue services and weather forecast. The concept is based on the idea that the customer or authority that is responsible for the critical customer has the main responsibility of maintaining the criticality information like the time that site can be without electricity supply, the so called critical time.

The concept of the situation awareness system takes that on account by combining information from multiple sources such as the DMSs of different DSOs into one view. Additionally, the information shown on the system can be customized based on the user or user group, e.g. user can choose their own operating area to reduce the amount of the useless information or information layers that they want to see. The method helps the users to project future events by warning if the critical site is exceeding its critical time.

In this method, there is possibility to add information about disruptions of other critical infrastructures like mobile network. For example, the information about the outages of mobile and electricity networks can be combined with criticality information. These functionalities can be important with home care patients who have safety phones or buttons.

B. The main functionalities of the demonstration

To test the concept a demonstration of the situation awareness system was created. The developing process of the demonstration has been iterative based on the Action Design Research method (Sein et al. 2011); where the users of the system are involved in the development process from beginning. The results of the interviews and workshops were used in the developing process. The main purpose of the demonstration is to test how the resilience of the society and the restoration process of electricity network can be improved.

The demonstration has a web based user interface (illustrated in fig. 3). It presents the outages of electricity network (grey symbol) on a transformer level map. Additionally, the system combines the information about disruptions of mobile network to the same view. The view is personalized according to the needs of information that user groups have e.g. municipality sees only their own sites and fire and rescue service sees all critical sites (symbols with yellow frame) in their operating area. Users can choose themselves what information layers they want to the system. Further, some of the information is personalized based on the user groups like critical sites. The personalization is made to reduce unnecessary information. (More information from Krohns-Välämäki 2016).

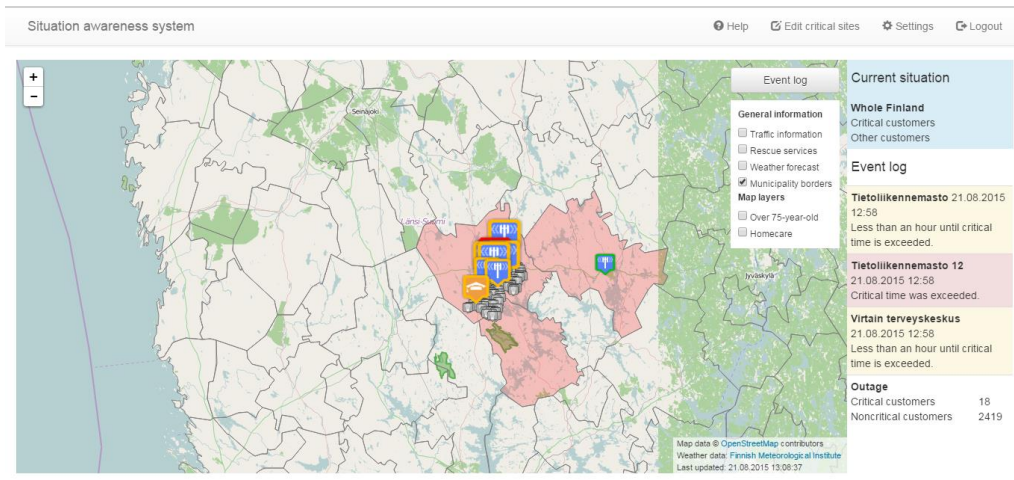


Fig. 3 User interface of situation awareness demonstration

6. The benefits of the situation awareness system to the society

Different versions of the demonstration were presented for users at interviews and workshops. Several benefits of the system were found. When presenting the demonstration in the interviews, the response to the demonstration was mainly positive. Especially the municipality thought that situation awareness system would highly improve their operability in disturbances. Fig. 4 illustrates how the system simplifies the information exchange in disturbances (compared with Fig. 1).

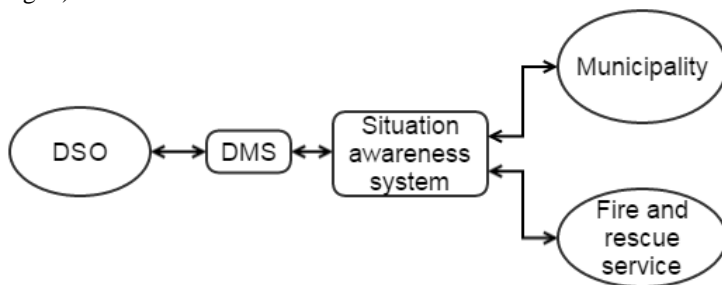


Fig. 4 Sources of the situation awareness with situation awareness system.

For fire and rescue service, the information about the estimate duration of the disturbance is in an essential role. Thus, they can prepare for increasing amount of their duties and call more officers to duty. The combination of the information of multiple DSOs decreases the amount of the information sources of fire and rescue service. Additionally, it helps them to detect and contact the right DSO e.g. when they get an emergency call about trees on lines. This will decrease the workload of fire officers. With the situation awareness system, the fire and rescue services can increase their help to the municipality, e.g. they can plan the evacuation with municipality earlier.

Nowadays, the municipality uses their customer databases, a map system and the web page of the DSO to locate the people who need help. With the situation awareness system, the municipality

can see all information from one view. The integration of the information about critical sites and outages can be used e.g. to plan evacuation. When the municipality has the warning about the critical site, which critical time is going to exceed, they can start their process to help or evacuate the site. The layers of the location of all elderly residents and disabled people improve the capability of the municipality to focus the help on right. One major improvement to the operating capability of municipality is the information about the state of the safety phone customers. Municipality or safety phone operator can send someone to confirm the well-being of the customers who do not have electricity.

The system improves the capability of the municipality to help their home care patients. They can send representatives of the home care to make extra checking to their customers. Likewise, it enables the special health care to invite to hospital or to evacuate their patients how live at home and have equipment that requires electricity e.g. mobile respirator patients.

In addition to the health of the people, the system can help the municipality to maintain the operation of their critical infrastructure like water supply or sewerage. Warnings of the main sites of the critical infrastructure, helps municipality to backup them and to begin processes needed to substitute them e.g. to share water to residents.

Further, the system can be used for planning the procedures of the fire and rescue services or municipalities. Organizations can detect in advance, how the critical customers are located and what areas are the most vulnerable to disturbances. This information can be utilized e.g. to plan placement of the backup generation. Additionally, the system can be used to simulate disturbances. Thus, it can be used in training purpose. This can benefit the organizations when they plan co-operative procedures.

The presented method would improve the DSO to achieve the situation awareness from other organizations by combining all external information to the same view. The information achieved from the others would be more processed than at present e.g. the warnings of exceeding the critical time of the critical site. Nowadays, the information is more like data about different events and operators have to make these projections to the future by themselves. In complex situation like disturbance, these would decrease the amount of workload that operator has.

The situation awareness system can be used in restoration planning and network development to fulfill the requirements of the legislation. Additionally, the vulnerabilities on electricity network and areas with most vulnerable sites can be found. Based on this information the placement of the backup generation can be planned or to the decision of the cabling made.

The criticality database in the demonstration improves DSOs' information about sites that are highly dependent on electricity. DSOs can plan their restoration order based on this information. If the DSO has the knowledge that the critical site is evacuated, they can reprioritize the restoration order. Likewise, if the DSO knows that the critical site has backup generation, they can prioritize other sites in restoring order.

7. Conclusion

There have been several problems in information exchange between organizations in the disturbances of electricity supply. In recent years, the methods have been improved, e.g. DMS services are provided to local fire and rescue services. However, these methods are still shattered and inadequate. Municipalities have most problems with information exchange with DSOs, because they are using only the public web sites of DSOs.

The demonstration of the situation awareness system developed in this study shows how information exchange can be improved in disturbances. The main difference for the present methods is that the system includes the database of the critical customers. DSO can utilize this database to plan the restoration order. Additionally, the system combines the information from multiple DSOs and MNOs to the same view and filters it based on the operating area of the user. Thus, the workload of the system users will decrease. Compared to the present methods, the system processes the information to project the future e.g. warning if the critical time is going to exceed.

The benefits of the system for the society are high, e.g. evacuations can be planned in early state. The system helps DSOs to take the resilience of the society into account in restoration planning by recognizing the most vulnerable areas. Additionally, the system helps the DSO to fulfil the requirements of the new legislation.

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