Master's thesis

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Sunniva Helland Jerndahl

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NTNU
Norwegian University of
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Department of Design

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Design of insight tool for inspection and monitoring of the power grid

How can power grid companies predict and prevent outages?

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Submission date: March 2022
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Norwegian University of Science and Technology
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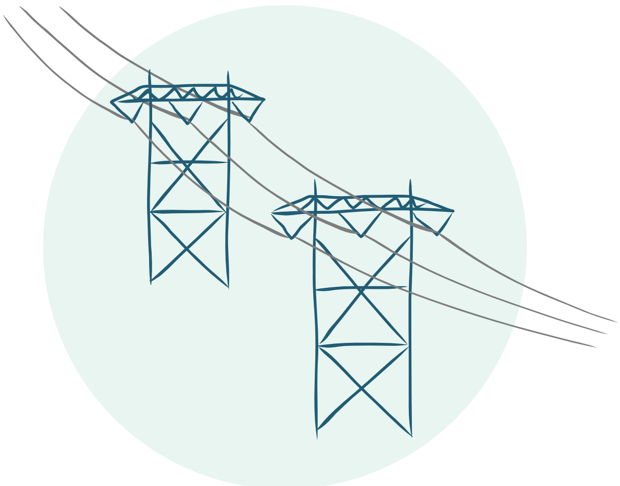

A master thesis written by Sunniva Helland Jerndahl
in collaboration with eSmart Systems

Norwegian University of Science and Technology

2022

Masteroppgaven er utarbeidet ved Institutt ved design på NTNU, 2021/2022. Denne rapporten tar for seg arbeidet og designprosessen med å utarbeide et konsept som kan bistå nettselskapene i å jobbe mer proaktivt med vedlikehold av kraftnettet, med mål om å forhindre utfall.

Takk til Ole Andreas Alsos for god veiledning og nyttige innspill gjennom et langt semester.

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En stor takk til min tålmodige ektemann og superpappa Kristian, og ikke minst til Tyra som har lyst opp hver eneste dag og gitt meg de fineste pausene fra arbeidet. En stor takk også til resten av familien for uvurderlig støtte.

List of acronyms

AEPR	Alarm and Event Processing Routine
AI	Artificial Intelligence
AMS	Advanced metering and control systems
AR	Augmented reality
DMS	Distribution Management System
EMS	Energy Management System
FE	FirstEnergy
GDTA	Goal Directed Task Analysis
GV5D	Grid Vision 5D
HCD	Human Centered Design
HSSE	Health, Safety, Security & Environment
ILE	Ikke-levert energi (Undelivered energy)
KILE	Kvalitetsjusterte inntektsrammer ved ikke-levert energi (Quality-adjusted income penalty for undelivered energy)
kV	Kilovolt
MISO	Midwest Independent System Operator
NIBIO	Norsk institutt for bioøkonomi (Norwegian Institute for Bioeconomics)
NVE	Norges vassdrags- og energidirektorat (Norwegian Water Resources and Energy Directorate)
SME	Subject Matter Expert
R&D	Research and development
SA	Situation Awareness
SAOD	Situation Awareness Oriented Design
SCADA	Supervisory Control and Data Aquisition
SE	State Estimator
T&D	Transmission and distribution

Abstract

The demand for electricity has never been higher, and is expected to continue to increase in the future. In a society that is undergoing a grand shift towards digitization and the demands of the green shift, society will continue to depend on a reliable power grid.

The power grid has been around for over 100 years, and has seen an enormous increase in both scope and complexity. The green shift will demand vast amounts of electricity, and the current infrastructure is vulnerable to both interruptions and overloading. To ensure reliable power deliveries, it is critical to be able to predict and prevent outages. This is primarily the responsibility of the maintenance departments of the different grid companies, but will also include inspectors and operators.

The power grid companies companies show signs of relying on technology driven design. Many of the challenges grid companies face today can be related to technology driven development. By readjusting to a user centered approach and implement situation awareness oriented design (SAOD) the industry can reduce the challenges related to vast amounts of data and high complexity.

In this thesis SAOD and user centered design is used to detect information requirements. A proposed holistic concept has been suggested based on this analysis, and a simple prototype has been developed to showcase possible scenarios.

Sammendrag

Etterspørselen etter strøm har aldri vært større, og alt tyder på at etterspørselen vil fortsette å stige drastisk også i fremtiden. Med den økende digitaliseringen av samfunnet og det grønne skiftet vil samfunnet fortsette å være avhengig av sikker strømforsyning for å kunne fungere.

Kraftnettet har eksistert i over 100 år, men kompleksiteten og omfanget har økt enormt i takt med etterspørsel og ny teknologi. Det grønne skiftet krever enorme mengder strøm, og infrastrukturen er sårbar for utfall og overbelastning. For å sikre sikker strømforsyning, må nettselskapene kunne forutse og forhindre utfall. Dette ansvar ligger i hovedsak hos vedlikeholdsavdelingen, men inkluderer også roller som inspektører og operatører.

Bransjen bærer i dag preg av teknologi-orientert design. Mange av utfordringene nettselskapene opplever i dag kan relateres til en teknologiorientert utvikling. Ved å endre til en brukersentrert tilnærming og bruke metoder innen situation awareness oriented design (SAOD) vil bransjen kunne redusere utfordringene knyttet til enorme datamengder og kompleksitet.

I denne oppgaven benyttes SAOD og brukersentrert design for å detektere informasjonsbehovene. Et tenkt helhetlig konsept er foreslått basert på dette, etterfulgt av en enkel prototype for å eksemplifisere mulige scenarier.

Avslutningsvis er det diskutert utfordringer og anbefalinger for en fremtidig helhetlig løsning.

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1

INTRODUCTION

Introduction

The 14th of august, 2003, a series of incidents resulted in one of the biggest power blackouts the world have ever seen. At 13:30 in Ohio, an EMS engineer at the Midwest Independent System Operator (MISO) went to lunch, unaware that his actions would be a part of a long series of incidents with fatal consequences. (Muir & Lopatto, 2004) He had just fixed a problem with their State Estimator (SE) tool, an application that determines the real-time state of the power system in a specific region. After making the appropriate changes, he forgot to re-engage the automatic periodic trigger, a trigger that runs the SE automatically every five minutes. (Muir & Lopatto, 2004)

At 14:14 the same day, operators at FirstEnergy (FE) were unaware that their "Alarm and Event Processing Routine" (AEPR), a key software program that provided visual and audible overview of their grid, began to malfunction.

Both the SE at MISO and the AEPR at FE experienced issues over the coming hours. At MISO the operators were at times aware of their issues, while the FE operators were unaware of the issues with AEPR for an hour and a half. (Muir & Lopatto, 2004)
As issues began to escalate, four FE transmission lines had outages due to contact with trees, further escalating the situation. These areas had been noted in flyovers in 2001,and 2002, and downplayed in a 2003 flyover, and had not been adequately trimmed. As these transmission lines had to handle increased loads, they sagged lower and short-circuited on trees. (Muir & Lopatto, 2004)

The primary causes of the outage are grouped into four categories.(Muir & Lopatto, 2004)

- The failure of FE and local power agencies to recognize the inadequacies in FE's systems.
- The inadequate situation awareness at FE, as they did not recognize the deteriorating condition of their system.
- FE's failure to manage tree growth near and below their transmission lines.
- The failure of the interconnected grid's reliability organizations in real time communication with the different entities.
-

The outage shows how the power grid is vulnerable when small issues combine and escalate. The 2003 Northeast blackout can be attributed to combined issues in communication, mismanaged maintenance and lack of situation awareness.

NTNU
Fakultet for arkitektur og design
Institutt for design

Masteroppgave for Sunniva Helland Jerndahl

Design av innsiktsløsning for inspeksjon og overvåkning av kraftnettet

Design of insight tool for inspection and monitoring of the power grid

Sikker strømforsyning er avgjørende for at dagens samfunn skal fungere, og etterspørselen etter strøm er økende. Kapasiteten i kraftoverføringen er presset, og nettet er sårbart for strømutfall.
Ny teknologi gir nye muligheter for innhenting og håndtering av data om strømnettets tilstand og risiko for feil. Bruk av for eksempel droner og kunstig intelligens kan bidra til å innhente og tolke data raskere og i større omfang. Med denne digitaliseringen og stor økning i mengde og variasjon av data, følger det menneskelige utfordringer i oppgaven med å håndtere og forstå situasjonen.

Oppgavens formål er å utvikle et konsept som skal bistå nettselskapene i å kunne forutse og forhindre strømutfall. Det skal undersøkes hvilke informasjonskilder som er relevante for nettselskapene for å gi de nødvendig innsikt om den fysiske tilstanden i nettet, samt relevante omgivelser, slik som vegetasjon.

Masteroppgaven vil blant annet inneholde:

- Innsiktsanalyse
- Idégenerering og konseptutvikling
- Prototyping og brukertesting
- Konseptforslag

Prosjektet gjennomføres i samarbeid med eSmart Systems og utføres etter "Retningslinjer for masteroppgaver i Industriell design".

Ansvarlig faglærer (hovedveileder ID): Ole Andreas Alsos
Bedriftskontakt: Kenneth Lindbeck-Dahlstrøm

Utleveringsdato: 26.08.2021
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Trondheim, NTNU, dato

Ole Andreas Alsos
Ansvarlig faglærer

Sara Brinch
Instituttleder

1.1 Project description

A reliable supply of power is paramount for the continued existence of modern society. The demand for power is rapidly increasing, and the power grid is already under pressure, and vulnerable to power outages.

New technology provides new opportunities for gathering and monitoring data detailing the state and potentials for defects in the power grid. The use of drones and artificial intelligence can help gather and quickly analyze vast amounts of data. This digitization and increase in data creates new challenges for the human operators that operate and manage the power grid.

The goal of this thesis is to develop a concept that can help power grid companies in predicting and preventing power outages. Information sources that are relevant for power grid companies to attain the necessary insight into the state of the grid and it's relevant surroundings shall be investigated.

In designing such a concept the gathering of insight is important. A Goal Directed Task Analysis shall be used as a primary process tool in order to understand the complexity of the system, and determine which sources of information a power grid company requires in order to perform proactive maintenance.

This project is in collaboration with eSmart Systems. Supervisor at the Institute of Design is Ole Andreas Alsos, and primary contact at eSmart Systems is Kenneth Lindbeck-Dahlstrøm.

1.1.1 Motivation

The story about the Northeastern Blackout has been a major source of inspiration in exploring how a lack of situation awareness can have serious consequences, and how design can play a vital role in such critical situations. The desire to explore how user-centered design can have an impact in a consverative and technology-driven field has been the basis for the theme of my master thesis.

The power grid is a vital piece of society, and the infrastructure it provides is one of the foundations of modern society. It is easy to take the continuous availability of electricity for granted, but imagine how difficult life would quickly become if the access to electricity vanished. The power grid is vulnerable to outages, and a steady increase in demand, driven by the green wave in particular, can be a risk to the reliable delivery of electricity. Several large outages in recent years have cost many lives and vast amounts of money across the globe.

Enormous developments in the possibilities provided by technology brings new challenges for those who manage the increased information flow and data load. Design of safety critical systems is a fairly new field, and there is currently not a lot of research on situation awareness in power grid monitoring and power grid operations. The power industry is traditionally a conservative industry that show signs of technology-driven development, and it is reasonable to believe that a focus on user-centered design will be important in the future, so that human operators with human limitations can properly assess the state of the power grid, and make accurate predictions on the results of their actions.

“Most industrial accidents are caused by human error. Estimates range between 75 and 95 percent. How is it that so many people are so incompetent? Answer: They aren’t. It’s a design problem”
- Don Norman (Norman, 2013)

To contribute in making safety critical systems more resistant to so-called human errors through design is both motivating and challenging.

1.1.2 The design role

For this thesis I had the opportunity to participate in both the Skogrisk AI and Grid Vision 5D projects. These projects are described in section 1.2. From the thesis outline Grid Vision 5D was the most relevant project, and I was allowed to participate in a design role leading design workshops. eSmart Systems had defined goals for this project, and fixed targets for development. From a design point of view, I wanted to use the insight phase of my project to further define the concept of my own project. In order to remain unbounded by the scope of the GV5D project I chose to not follow their directions, as I believed this would provide more opportunities for academic development. Being involved in the design processes of GV5D was still very valuable and provided useful insight that I used as a basis to design the solution I believe includes the needed tools and information for grid companies.

Being a designer in a fairly conservative field was an exciting task. eSmart Systems is an ambitious company, with a great focus on innovation. The grid companies on the other hand are more conservative, even though they show interest in the opportunities provided by new technological solutions. Having the opportunity to be a part of introducing a creative process into the development of new solutions was a rewarding and interesting experience.

1.1.3 Limiting scope

To define the theme of the thesis, it was initially determined to limit the scope to the regional and distribution grids. The transmission grid is owned by the state, and due to the differences between the transmission grid and the lower voltages it was a natural choice to remove it from the scope of the thesis. This was important for the work in the insight phase, as private grid companies that operated both regional and distribution grids were involved in the eSmart Systems projects. Furthermore the thesis has been limited to deal with monitoring and maintenance, with a goal of further limiting this division in the preliminary parts of the insight phase.

During the insight phase it was quickly determined to limit the scope of the thesis to maintenance tasks in a grid company. This was beneficial, as it aligned with the focus of the eSmart Systems projects, and these then provided valuable insight into the target users. The choice of focusing on maintenance tasks felt natural, as the primary goal of maintenance is to prevent issues from occurring by ensuring that the power grid is up to date. In contrast, the operators in an operating center focus on returning power to the grid when an outage first occurs.

1.2 Design process

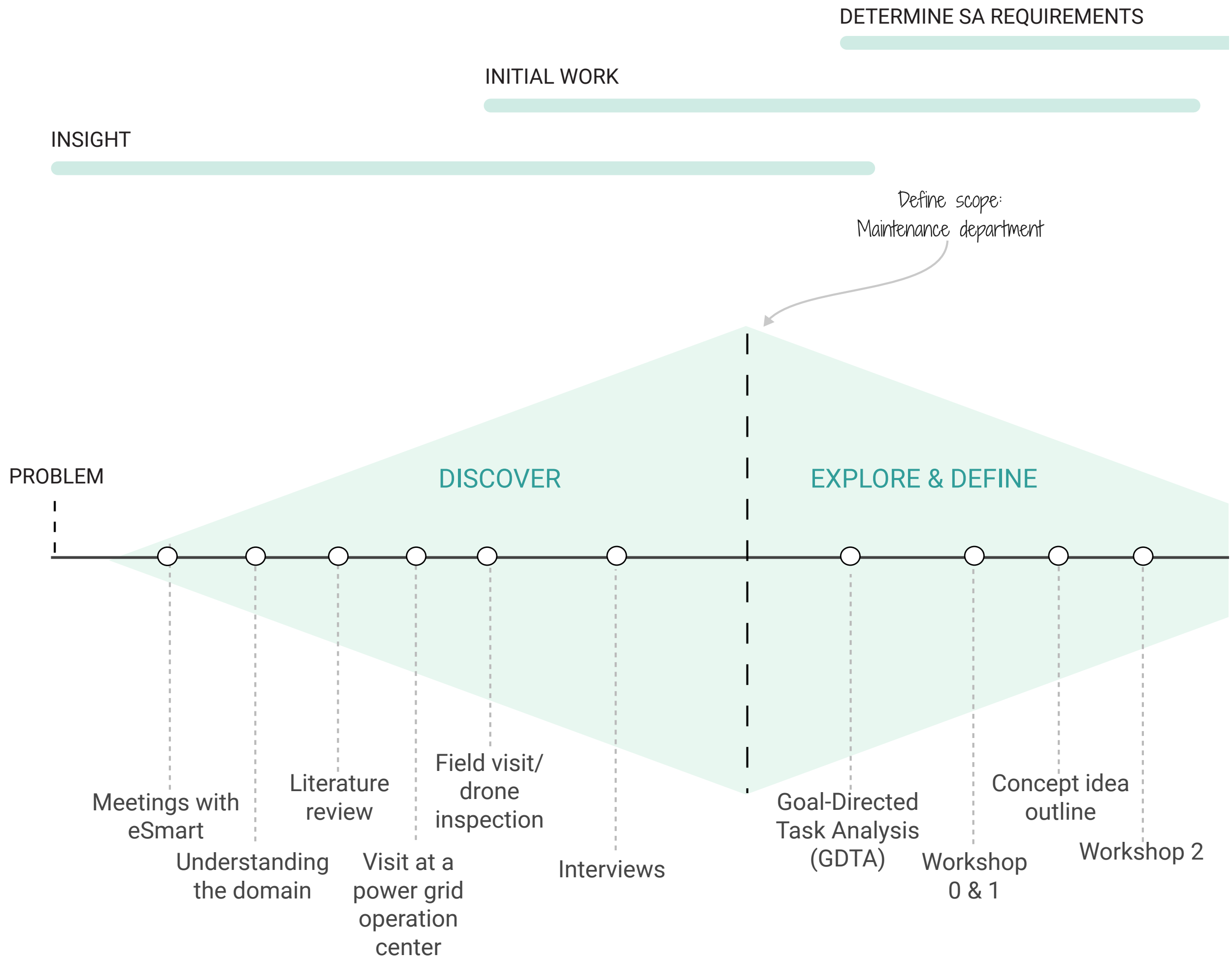
The design process of the thesis has been based on user-centered design, primarily drawing methodology from Situation Awareness oriented design.(Endsley & Jones, 2012)

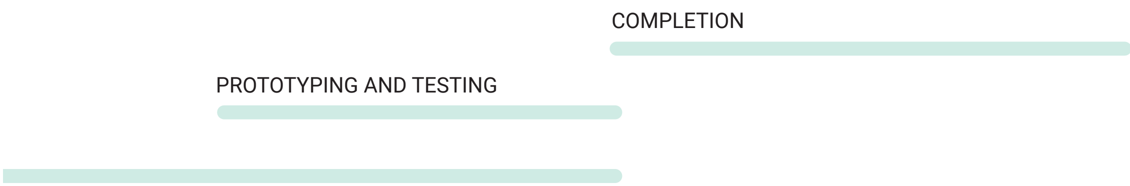
The first phase of the process was centered around gaining insight into the domain, and exploring the challenges faced by grid companies. This exploratory phase showed many potential focus areas, and it became necessary to further limit the scope of the project and define the central issue of the thesis. From there, potential solutions were explored and a holistic concept was chosen.

The concept was illustrated, and a simplified prototype was built to correspond to a set of chosen scenarios. This process, where exploration and development is done in two phases with a subsequent limitation of the scope, follows the double diamond process. (Design Council, 2015) The process is visualized in figure 1.1

1.2.1 Process timeline

The width of the diamonds represent the time spent on each part of the process. The majority of the time was spent on the GDTA as part of the work of determining the Situation Awareness requirements. The GDTA was used and refined throughout most of the project.





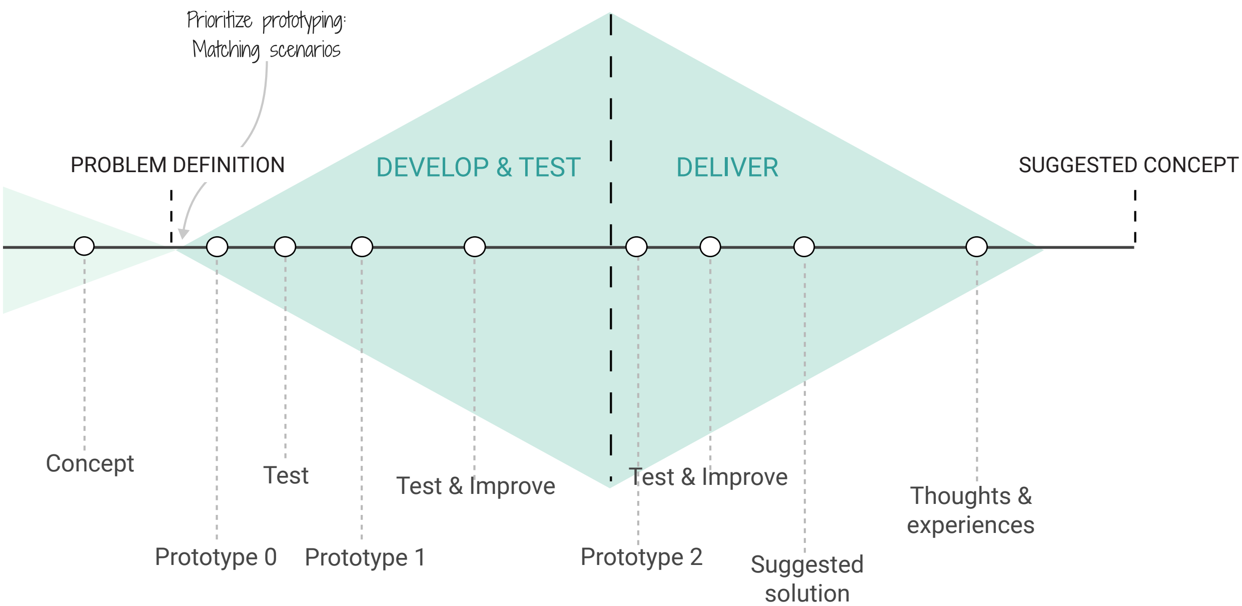


Figure 1.1: Double Diamond design process

1.2.2 Methods

Literature review
How: Lese relevant faglitteratur og rapporter om kraftnettet, situasjonsforståelse og design av sikkerhetskritiske systemer
Why: For å få bedre forståelse av domenet i forkant, slik at utbyttet av intervjuer og feltarbeid i innledende fase ble større.

Interviews
How: Prepared and unstructured interviews with focus on goals and information requirements rather than technology, as suggested by Endsley and Jones (Endsley & Jones, 2012)
Why: To gather insight and information for a GDTA (Endsley & Jones, 2012)

Design workshops
How: Remote design workshops with different exercises together with participants representing the user group.
Why: To get valuable insight from the experts.

Affinity diagramming
How: Externalize and meaningfully cluster observations and insights into categories. (Martin & Hanington, 2012)
Why: To capture research-backed insights and requirements.

Field Visits
How: Join a drone inspection and visit a power grid company.
Why: To see how different roles within power grid maintenance work, and see examples on what challenges they face today.

GDTA
How: Explained in chapter 4.
Why: To identify what information is needed for the operator to achieve his/her goal. (Endsley & Jones, 2012)

MoSCoW
How: Sort requirements in the categories “Must”, “could” and “should”.
Why: To sort the requirements by importance.

Concept map
How: Connect ideas, objects and events in an organized map.
Why: To absorb new concepts so that new meaning can be made. (Martin & Hanington, 2012)

Personas
How: Describe the user through bio, needs and pain points.
Why: To humanize design focus. (Martin & Hanington, 2012)

Scenarios
How: Outline a narrative that explores the user’s experience as the user engages with the system.
Why: To make design ideas explicit and concrete. (Martin & Hanington, 2012)

Prototyping
How: Sketch the ideas in the form of a prototype, to test and get feedback, and then improve the prototype. Iterative process.
Why: To visualize ideas and user interface, and get feedback from testing.

User testing
How: Test ideas, context and user interface in a prototype.
Why: To get feedback and improve the prototype.

1.3 About eSmart Systems

eSmart Systems is a software company focusing on machine learning and AI, and how these technologies can help power grid companies improve their inspections and maintenance work. Starting in 2012, eSmart Systems has developed software solutions in collaboration with power grid companies. They started out with a technological focus on how an AI centric software product could become a full scope solution for the utility industry. The ambition was to reach a high level of automation of the human processes related to inspection of power grids. In the first stage of this development eSmart focused on how several machine learning technologies could be used for detecting electrical components and defects in the grid.

They focus heavily on new technology and the new opportunities it brings. The majority of their employees are data scientists, developers and computer engineers. eSmart Systems deliver software products that help provide more efficient operation and maintenance of power infrastructure and better usage of energy resources. Artificial Intelligence and machine learning is the basis for the tools and services they provide, primarily to companies in Norway, Europe and the USA.

Their primary focus is on being a leader in the digital transformation, and as a part of that goal, they are committed to actively participating in national and international R&D projects. SkogRiskAi and GV5D are two such projects, and these ongoing projects have had a great impact on the insight phase of this thesis. GV5D is implemented in cooperation with Norwegian power grid companies, and is covered by the power grid companies' R&D-scheme (Power grid companies can spend resources on R&D without impacting their profitability rating, provided the project is approved by The Research Council of Norway).

After some years with R&D projects and proof of concepts together with the utility industry in Norway, Europe and US, they changed their approach from "AI can solve everything" and at a significant scale replace human workers to so-called Collaborative AI. Through Collaborative, AI users (such as SME's) and AI work together and take advantage of each side's complementary strengths.
As a consequence of their focus on technology, eSmart Systems show signs of being primarily technology-driven in their development processes. Up until 3 years ago eSmart Systems had no internally employed designers. After the acquisition of Verico in 2021, they now have 115 employees, of which two are designers. In addition they hire one full time design consultant.

Verico has since its founding in 1999 specialized in products and services targeting enterprise asset management for various industries, including electric power generation and distribution. They have completed projects on both the transmission and distribution grid, and have therefore worked with both Statnett and other local and regional grid companies in Norway. (Verico, n.d.) Verico employees provided valuable insight for this master thesis, including workshop participation, product demonstrations, and with useful feedback and comments throughout the project.

1.3.1 AI and collaborative AI

According to Harvard Business Review (Wilson & Daugherty, 2018) collaborative intelligence where humans and AI are working together represents the most successful applied AI in businesses so far. It is very likely that AI is transforming, or is going to transform, all sectors of businesses the years to come.

The main findings from the research described in the report mentioned above is that companies that deploy AI mainly to displace employees will only get short-term productivity gains, while companies that focus on collaborative AI where humans and AI actively enhance each other complementary strengths will achieve the most significant performance improvements.

1.3.2 Grid Vision

Grid Vision is eSmart Systems' AI-based product for inspection of power lines and substations. (eSmart Systems, n.d.)
Most of the grid companies worldwide still use traditional inspection methods which are characterized by manual and costly processes. Grid Vision aims to optimize infrastructure inspections where the goal is better and quicker decision-making at lower costs. By using drones for image capturing, the need for manual top inspections where line workers climb the poles is significantly reduced. This is one example of how Grid vision can contribute to improve safety for lineworkers. The Grid Vision product is used both for high voltage transmission grids and distribution grids and consist of two modules, Grid Vision Inspect and Grid Vision Insight.

Grid Vision Inspect uses Collaborative AI as a key methodology to enable engineers and inspectors to perform high quality power asset inspections faster and with greater accuracy compared to traditional methods. Grid Vision Insight is used for improving the planning process and gaining better asset insight. Grid Vision Insight provides real-time birds-eye and analytical drill-down into inspected assets.

The goal is that through Grid Vision the power grid companies can reduce operating expenses, improve grid reliability, optimize investments in the grid and improve safety for line workers in the field.

1.3.3 SkogRiskAI

One of two eSmart Systems projects that have been involved in this thesis is the SkogRisk AI (Forest Risk AI). SkogRisk AI aims to use artificial intelligence to estimate the risk of trees hitting power lines. Managing vegetation, where the focus is to control and remove unwanted vegetation, is a crucial factor for power grid companies. Failure to remove unwanted vegetation can lead to tree falling hazards and destructive wildfires, as well as blackouts with potential huge economic loss for power grid companies. SkogRisk AI is managed by eSmart Systems in partnership with NIBIO and several grid companies as a research project to develop a solution that can help grid companies in vegetation management. The goal is to create a tool that can help prioritize where to direct their resources, and to more efficiently use the available forestry resources, as well as provide information to increase emergency preparations.

The primary focus of the research is in risk modeling, sourcing of data, and data capture methods, the usage of AI to determine tree properties, and how these data sources can be combined in a single software tool. The project hypothesis is that by combining existing sources of data (digital terrain maps, satellite images of forested areas etc.) with local drone footage, artificial intelligence can further improve the precision of risk models based on the complete dataset. (Forskningsrådet, n.d.)

Figure 1.2: SkogRiskAI Photo: eSmart Systems

1.3.4 Grid Vision 5D

The other project involved in this thesis is Grid Vision 5D. The purpose of this project is to explore potential sensors and other sources of information required to give operators necessary insight into the physical state of the power grid. In the context of the project, the state of the grid is defined by the physical state of the grid, transmission towers, components, vegetation and other relevant surroundings.

The project will explore how sensor data, satellite images, and 3d image data can be used to show the overarching state of the power grid. Artificial Intelligence and/or detailed analysis will then be used to convert the raw data into insight into the state of the grid.

From this insight, the probability of failure in different scenarios shall be estimated, and combined with the potential consequence of failure to provide a risk score for different poles and transmission line sections. The end goal is a tool that can visualize potential issues, state and risk in a new and groundbreaking way by providing grid companies a complete view on the state of the grid in 1d, 2d, and 3d views at different levels of detail. This allows grid companies more control and precision when planning, and prioritizing inspections and maintenance.

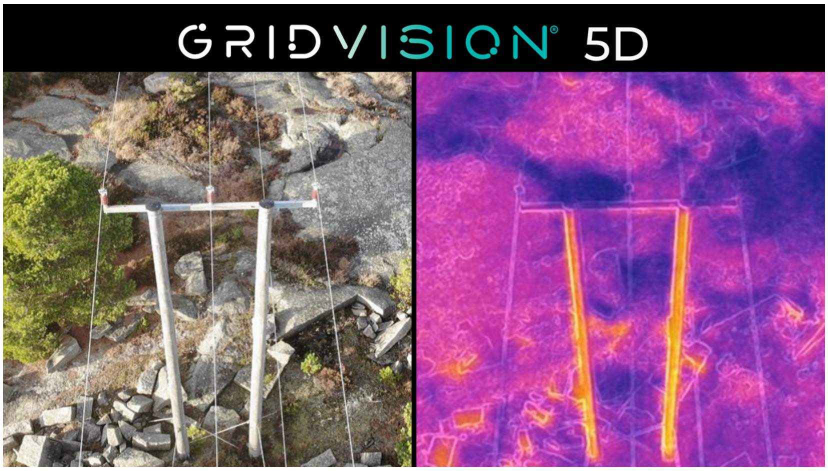


Figure 1.3: GridVision5D Photo: eSmart Systems

2

INSIGHT

Insight

To gather more insight into the domain, academic literature and relevant information was acquired and processed. Reading about the field to increase insight was of great help before the preliminary work with interviews and field work began. This is in accordance with the recommendations of Jones and Endsley (Endsley & Jones, 2012), in order to gain as much insight as possible from the interviews. Familiarity with how the power grid operates, and the terms used, increased the output of the research.

The power grid is a highly complex system, so in order to build as much detailed knowledge as possible it was decided to primarily focus on the regional and distribution grids in addition to maintenance and operations. Early meetings with eSmart Systems were also of great help in order to better understand the systems involved.

2.1 The Power Grid

A reliable power supply is a crucial aspect of modern society, and society relies on constant access to electricity. The modern power grid is built with these factors as main criterias, and is a resilient system with strong redundancy elements.

The demand for electricity is ever growing, and showing no signs of decreasing. As society is undergoing the green shift the power grid must continue to support this continued expansion. To ensure a continuous supply of electricity, the power grid is under constant monitoring. Electricity produced must match the total consumption, on both a regional and national level. The shift towards digitalization is also reaching the grid companies, leading to new opportunities and challenges for monitoring and maintenance. (Statnett, 2021)

In Norway, hydroelectric power is responsible for 90% of power generation. (Statkraft, n.d.) These hydroelectric power plants are primarily located far away from the consumptions, so the Norwegian power grid must allow for large distances between production and consumption of energy. These distances often traverse difficult terrain that introduce challenges for maintenance and inspection. Mountains and elevated areas can be difficult to reach, while transmission lines through forests require careful management of nearby vegetation.

As the world transitions towards the green shift, electrification of sectors that currently use fossile fuels is gaining traction. This would lead to an increased demand for electricity, that the power grid must be able to support. (Kringstad & Holmefjord, 2019)

2.1.1 Power Grids in Norway

The Norwegian power grid is subdivided into three defined grid levels with different responsibilities and owners. (Olje- og energidepartementet, 2019) The **Transmission Grid** is responsible for connecting producers and consumers spanning the country. The Transmission grid is operated by Statnett, and also includes responsibility for operating the international grid connections.

The **Regional Grid** ties the other two grid levels together, with voltage levels between 33kV up to 132kV. The regional and distribution grids are operated by grid companies that vary greatly in size from local companies with a few thousand customers, up to companies with several grid areas that have more than 100 000 customers.

The final grid level is the **Distribution Grid** that is responsible for distribution of electricity to the end consumers. The grid encompases both high and low voltage areas, where high voltage parts are from 1kV up to 22kV, and low voltage is from 1kV down to the 240v that most end users see. (Olje- og energidepartementet, 2019)

Since adopting the EU's 3rd Energy Package, the Norwegian energy law limits ownership of the Transmission grid to companies that hold a license. Currently, only Statnett holds such a license. (Lovdata, 2021c)

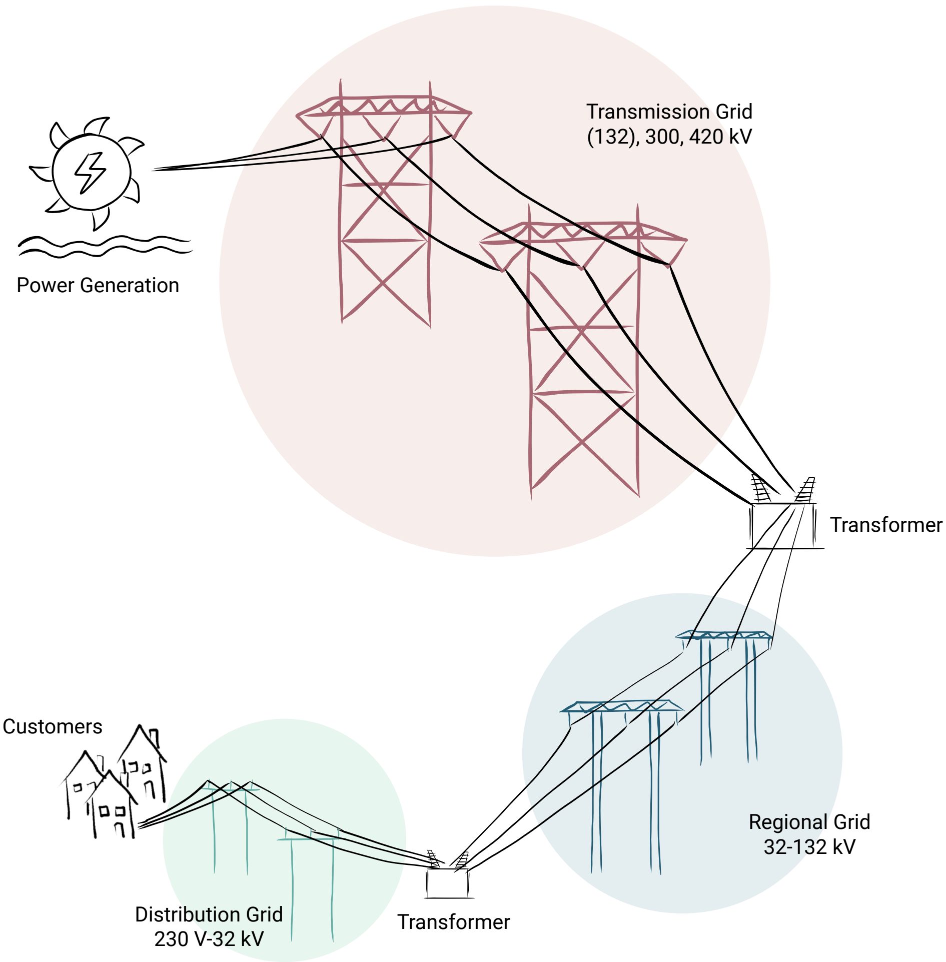


Figure 2.1: The Norwegian power grid

2.1.2 Power grid monitoring and operations

Operations of the power grid is characterized as a real-time system, where the ratio between produced and consumed energy must be balanced immediately at all times. This balance must be actively maintained, and all deviations and outages must be dealt with rapidly. The task of maintaining this stability is referred to as power grid operations, and requires constant monitoring of the power grid in order to balance the system.(Frøystad et al, 2018)

To gather real time data about the power grid, grid companies use several independent systems. The two primary systems used are the Distribution Management System(DMS), and the Supervisory Control And Data Acquisition (SCADA) systems. DMS represents the topology of the grid, so that potential consequences of changes in the grid can be visually represented on a map view.

SCADA is a system for connecting with remote data acquisition points, and remote control options such as actuators. Automation and remote control is available for transformer stations, but most of the smaller units in the grid are manually operated. Currently, the DMS system is not allowed to directly access the SCADA switches, but this type of automation is under consideration.(Frøystad et al, 2018)

2.1.3 Power grid monitoring and operations

The introduction of new technology and the increasing trend of digitization is also reaching the power grid sector. The power grid sector is historically a conservative sector, and is traditionally slow to adopt new technologies, often due to security and stability concerns. (Lysne et al, 2015)(Frøystad et al, 2018)

With the increase in data from new sensors and new technologies, the tools used by grid operators also need to adapt and improve. The design of these tools will be a continuous process where improvements can be made in order to help the operators maintain a stable and efficient power grid. With new technology these tools can further aid in predicting and preventing issues, leading to a more stable and robust power grid.

2.1.4 KILE

KILE-costs is an important metric for the power grid companies. The KILE is a metric that measures the cost of non-delivered energy (Ikke-Levert Energi), and is an economic reduction of income applied to all grid companies as an incentive to ensure socioeconomically optimal reliability of delivery. (RME, 2021)

The goal of the KILE scheme is to ensure grid companies prioritize reliability and continuous delivery when planning expansions and maintenance. A grid company's total outage cost is determined by summing the cost for all outages over a calendar year. The cost of each outage depends on several factors. (Lovdata, 2021b)

The simplified version is that the number of affected customers is the driving factor, adjusted by the correction factor. The correction factor is valued differently for different types of customers. The potential customers are: agriculture, households, industry, trade and services, public entities, and industry with electricity-driven processes. (Lovdata, 2021b)

2.1.5 Cause of operational disruptions

Statnett provides a yearly report on the cause of operational disruptions on the power grid. The latest published report is from 2018 (Statnett, 2018a)(Statnett, 2018b). A request for more recent data was sent to Statnett, but they did not respond.

The report is in two parts, and covers different parts of the power grid. As the report predates the current grid division, the report is separated into a high voltage and a low voltage section. Causes are listed by number of incidents, as well as by the amount of non-delivered energy for each cause. Out of these numbers, the amount of ILE for each cause is of the most importance, as they represent the outages that were difficult to either locate or quickly repair.

From figure 2.2 and 2.4, we see that for both the high and low power sections of the grid the surroundings are the cause of the most ILE. From figure 2.3 and 2.5, we see that among the causes listed under surroundings, vegetation is the largest contributor to ILE. From this, it is clear that reducing the impact and frequency of vegetation outages can save grid companies a lot of KILE every year, making it an important area of focus.

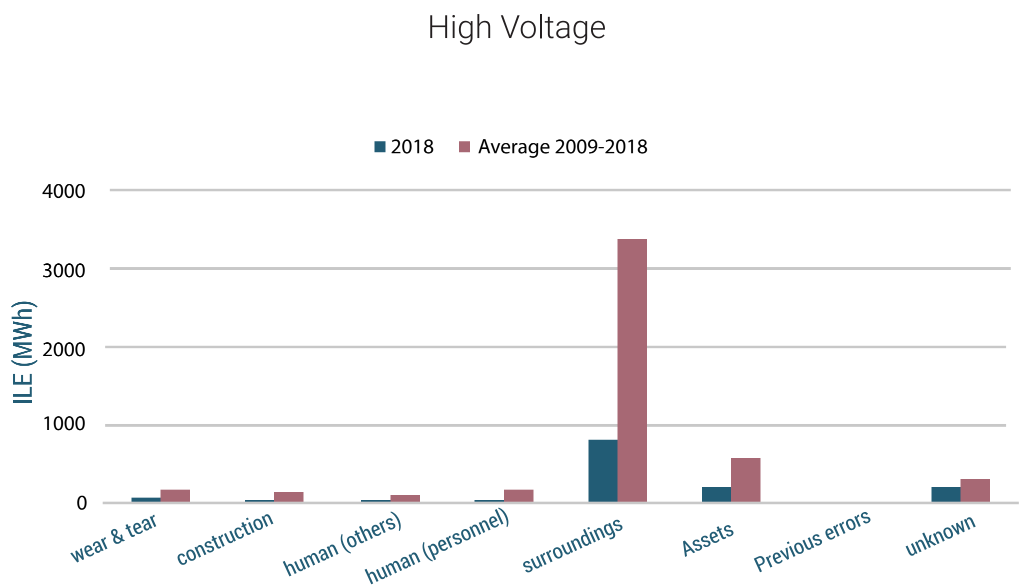


Figure 2.2: Causes of outages by ILE (Statnett, 2018a)

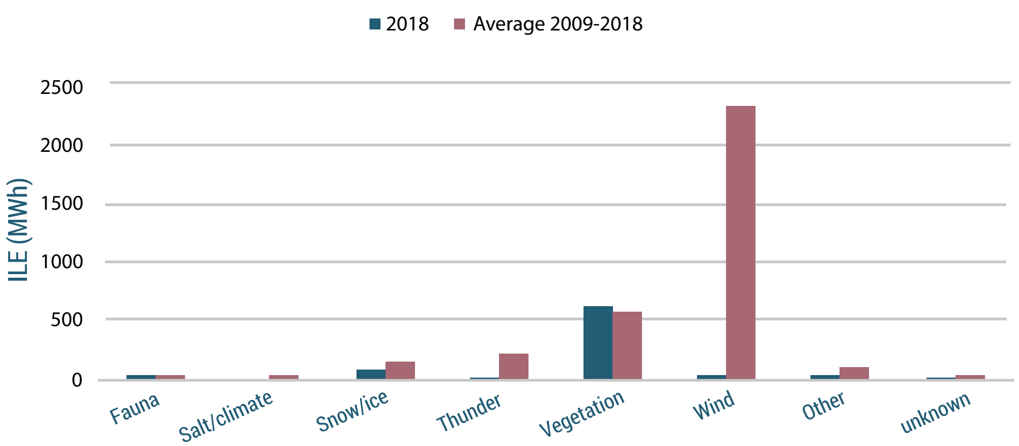


Figure 2.3: Causes within surroundings (Statnett, 2018a)

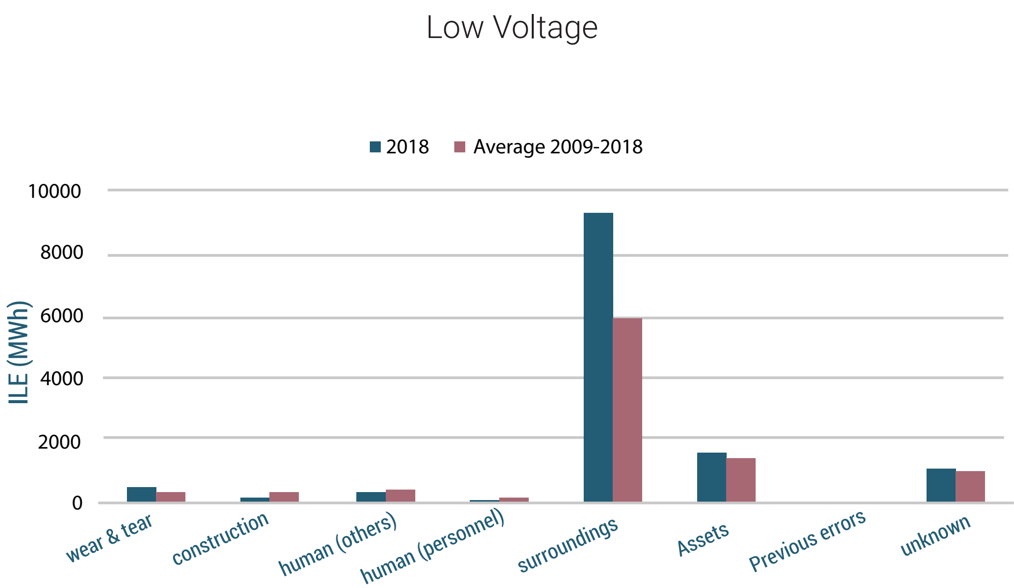


Figure 2.4: Causes of outages by ILE (Statnett, 2018b)

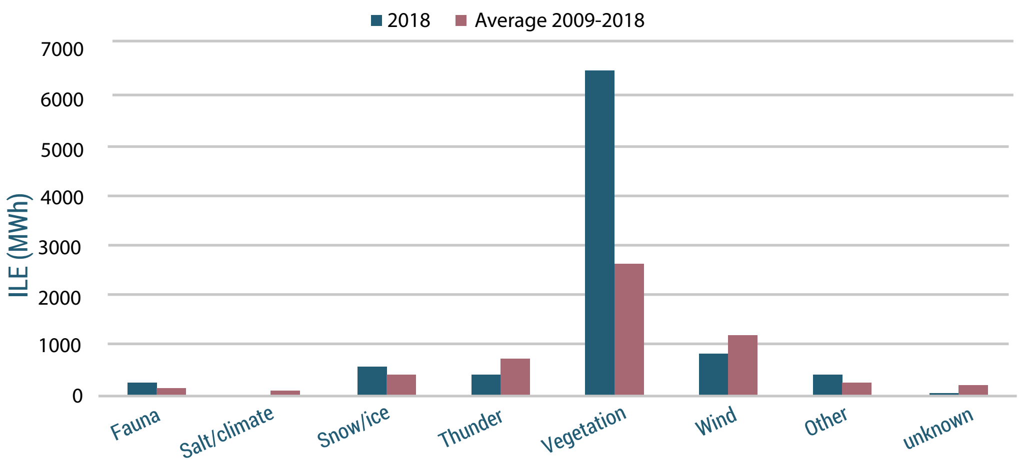


Figure 2.5: Causes within surroundings (Statnett, 2018b)

2.2 Design Theory

The academic literature with the most influence on this project was «Designing for Situation Awareness» (SAOD) by Endsley and Jones (Endsley & Jones, 2012)
SAOD builds on the concepts presented in Human Centered Design (HCD), and is primarily used in designing control rooms for operators in various fields. Despite maintenance workers being chosen as the user group, it was decided to use the same approach, as situation awareness is a vital property for maintenance workers as well. The maintenance department is more suited to predict and prevent outages, as the operations centers main focus is to restore power supply when outages have already occured.

2.2.1 Human centered design

To better understand Human-centered design and situation awareness oriented design, it is useful to explain technology-centered design, which is the most common design approach when designing systems. (Endsley & Jones, 2012)

In technology-centered design, sensors and systems are added to perform each function, and provide a display for each system to inform its status to the operator. The more technological possibilities, the more displays, and the more data and information for the operator to handle. (Endsley & Jones, 2012)

Human-centered design will achieve more efficient systems, as it challenges designers to adapt the interface to the capabilities and needs of the operators. By integrating information in ways that fit the goals, tasks, and needs of the users, we can reduce errors and improve productivity. (Endsley & Jones, 2012)

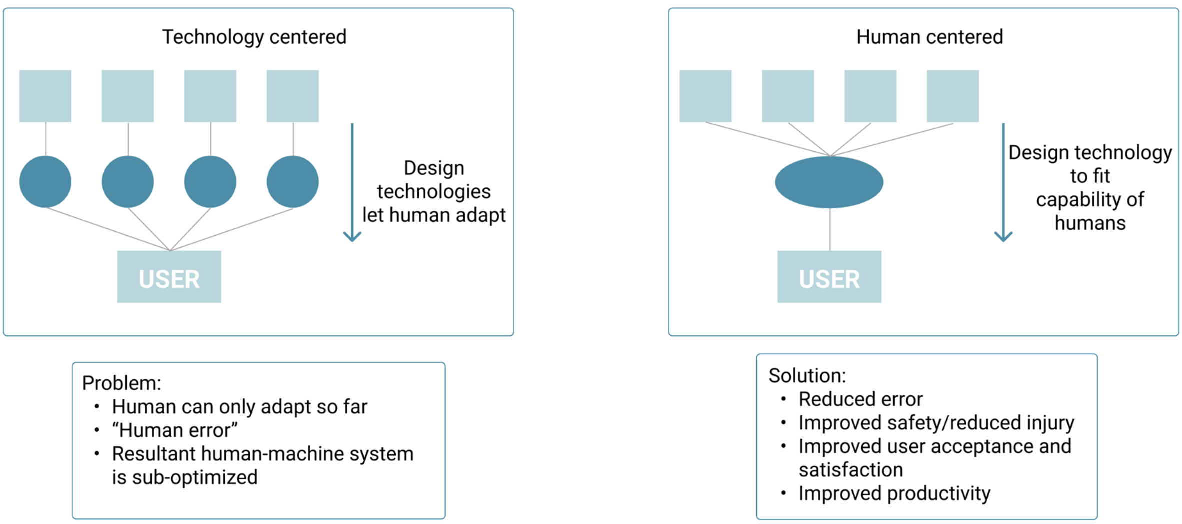


Figure 2.6: Technology centered vs human centered. (Endsley & Jones, 2012)

2.2.2 Situatuion Awareness

The human brain has certain limitations to process information. Mental workload is a well-known concept in human factors research, describing the relationship between the demands of tasks imposed and the limited information processing capacity of the brain (Wickens et al., 2015)

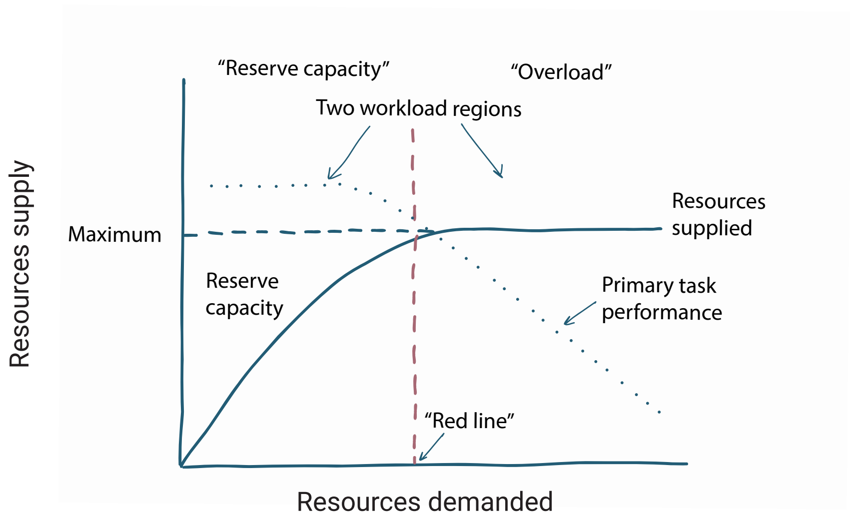


Figure 2.7: Schematic relationship among primary-task resource demand, resources supplied, and performance, indicating the "red line" of workload overload. (Wickens et. al, 2015)

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" (Endsley, 1988, p.1)

The formal definition of SA breaks down into three levels (Endsley & Jones, 2012):

Level 1: perception of the elements in the environment
Level 2: comprehension of the current situation
Level 3: projection of future status

Level 1 is about perceiving the status, attributes and dynamics of relevant elements in the environment. This perception may come through visual, auditory, tactile and other senses. Level 1 SA is not only perceived through electronic display, but also from the environment, for example by looking out the window. Verbal and nonverbal communications with others is also a way to perceive information that contributes to level 1 SA. The SA requirements are different for each domain and job type. (Endsley & Jones, 2012)

Level 2 is about understanding what the data and cues perceived mean in relation to relevant goals and objects. Comprehension of the current status requires comparison of level 1 elements to one's goal. (Endsley & Jones, 2012)

Level 3 is about predicting future status. Once knowing what the elements are (level 1) and what they mean in relation to the current goal (level 2), level 3 is achieved when the person is able to predict what the elements will do in the future. (Endsley & Jones, 2012)

In an examination of SA errors in aviation, 76% were found to be related to level 1 SA, not perceiving needed information. 19% were related to problems with level 2, and only 6% were found to be problems with level 3.(Jones & Endsley, 1996) This highlights the importance of focusing on all levels.

2.2.3 SA demons

SA is challenging for many reasons, and the factors that undermine SA are by Endsley and Jones referred to as SA demons. ((Endsley & Jones, 2012) The most important SA demons are:

- Attentional tunneling
- Requisuite memory trap
- Workload, anxiety, fatigue and other stressors (WAFOS)
- Data overload
- Misplaced salience
- Complexity creep
- Errant mental models
- Out-of-the-loop syndome

The most prominent of these in T&D operations are data overload and misplaced salience. (Endsley & Connors, 2008) (Endsley & Connors, 2014)(Connors et al, 2007) (Jerndahl, 2021) In the Northeast blackout, the out-of-the-loop syndrome was found to be in the center (Connors et al., 2007) Complexity creep is also of great importance, as the monitoring of power grids requires handling large amounts of data from different sources. These four SA demons are further examined in the following sections.

Data overload
When the amount of data outpaces the ability of a person's sensory and cognitive system, data overload is the result. The human brain becomes a bottleneck, and achieving good SA is difficult. (Endsley & Jones, 2012)

Misplaced salience
When flashing lights, moving icons and bright colors are overused, the brain uses significant cognitive resources in blocking out all the competing signals to attend to desired information.(Endsley & Jones, 2012) Lack of standardization and consistency is a common challenge for operators today, as different systems use different color schemes, alerts and animations. (Connors et al., 2007)

Complexity creep
Complexity creep is related to data overload. Complexity complicates people's ability to form sufficient internal representations of how systems work. Complexity creep can slow down the ability to take in information, but primarily it undermines the ability to correctly interpret the information, and to project future status. Complexity creep is therefore mainly a threat to level 2 and 3 SA. (Endsley & Jones, 2012)

Out-of-the-loop syndrome
Automation is what might result in the out-of-the-loop syndrome, for instance by leading operators to mistakenly believing the system is in one mode when it is not. (Endsley & Jones, 2012) Being out-of-the-loop might lead to lower SA if the operator does not understand the state of the system or how the automation is performing. Out-of-the-loop syndrome may not be a problem if the system is performing well, but can cause serious problems if the automations fails, as seen in the Northeast Blackout(Endsley & Jones, 2012)

2.2.4 Designing for SA

To get a clear understanding of the domain is crucial in order to design a system that supports SA. The goal directed task analysis (GDTA) is a powerful tool in developing this understanding. This will be explained further in chapter 4.

Endsley and Jones presents several general design principles for creating systems that improves the operators SA (Endsley & Jones, 2012) :

1. **Organize information around the operator's goals**, rather than techonology-oriented displays based on sensors or systems. Organize the information so that the information needed to achieve a particular goal is co-located.

2. **Present Level 2 information directly to support comprehension**. As the operators ability to process and remember information is limited, it is better for the operators SA if information is presented in terms of level 2 SA requirements.

3. **Provide Assistance for level 3 SA projects.** By directly providing tools to support projections, the mental workload requirements of projecting future states of the system can be lowered. This makes it easier to attain level 3 SA, in particular for less experienced operators.

4. **Support Global SA.** Prevent information from being limited to singular elements, as this can lead to operator focus being too narrow. Seeing the whole picture is an important part of SA.

5. **Support trade-offs between goal-driven and data-driven processing**. As the system should be designed around operator goals, support should also be given to processes that support data driven processing, so that the two processes complement each other.

6. **Make critical cues for schema activation salient.** In complex systems, mental models and schemata are thought to be key features in achieving higher levels of SA. The interface of these systems should be designed to highlight the critical cues needed for these mechanisms.

7. **Take advantage of parallel processing capabilities.** Systems should take advantage of the operator's capacity to process both visual and auditory information. Systems should be designed so that this parallel process directly benefits SA.

8. **Use information filtering carefully.** In complex systems with large data flows it is important to be careful when filtering information not related to SA needs. It can be difficult to accurately determine what information to filter out, and information that is actually valuable may be lost. (Endsley & Jones, 2012)

3

INITIAL WORK

Initial work

The initial work consisted of gathering knowledge about the domain. Different methods were used, with a goal of better insight into the user group and their needs. A field visit in order to inspect parts of the distribution grid and previous incident sites was of great value in order to better understand the domain. A later visit to a power grid company provided great insight into how operations and maintenance work is performed in day to day operations. Design workshops were held with both eSmart employees and external grid company representatives related to the GV5D project. In addition, participation in user forums and access to technical workshops provided more insight into the possibilities of the new technologies, as well as how eSmart collaborated with grid companies in their joint projects. Finally, a demonstration of the existing software that Verico has developed provided more insight into what type of solutions the grid companies actually need. The shown software is a solution the grid companies use today, and that is highly regarded.

3.1 Field visit

To better understand how field inspections are performed, a field visit was chosen as a suitable course of action. A drone pilot was chartered by eSmart Systems and a partnered power grid company to collect images from an area with recent power outages. The objective was to gather information about the power outages through image data. Scientists from NIBIO were also present, as they participated in eSmart Systems initiative SkogRiskAI.

Four locations that had caused outages during the past year were inspected during the field visit. The locations were limited to a regional area at Østlandet, and the locations were all visited during the same day. At all four locations the power outage had been caused by fallen trees hitting power lines, the most common cause of power outages in Norway. (Statnett, 2018a)

During the field visit the drone pilot and the NIBIO scientists discussed issues and shared insights. Active vegetation management along power lines is a necessity to prevent trees falling on power lines, but is limited by both environmental and economic concerns.

Location 1:
The first case of trees on line was caused by damaged roots. This was primarily caused by rot/fungus and a subsequent carpenter ants infestation. The topology of the region also played a part, as the power lines were on flat ground, bordered by a steep vegetated slope, with the fallen tree located fairly high up on the slope. The day of the outage the area had winds of up to 10m/s, possibly causing the fall Preventative tree clearing had been planned for the area, but had to be delayed due to finding a common buzzard nest in the area.

Figure 3.1: Location 1, field visit

Location 2:
Preventative tree clearing had already been performed near the second location, however a small triangle of forest was kept intact. This tree cleaning was done by the landowner, without notify the power grid company. The other side of the lines was also cleared, leaving the spared triangle more exposed to wind. The remaining trees then went from low to high risk, At night during winter a spruce fell, pulling the lines down with it, causing a very expensive power outage for the power company. At the time of the tree fall, snow was not a contributing factor, leaving wind as the primary cause. On the day of the outage, winds of up to 9 m/s were recorded in the area.

Location 3:
The third case could also be caused by rotten roots causing the tree to topple. In the first two cases the winds in the area were recorded at up to 10 m/s. NIBIO researchers suspected ash dieback (fungal disease) to be the root cause for this case. The area is environmentally protected, and it is desirable to limit any forestry in the area. Rowan trees in the area are not touched, as they do not grow tall enough to threaten the power lines, and help in limiting the growth of other trees around them. Moose in the area also aid in limiting local vegetation.

Figure 3.2: Location 2, tree clearing

Figure 3.3: Location 3, ash diebak

Location 4:
The fourth and final power outage location that was inspected stood out from the previous locations. This outage was caused by beavers having felled a large aspen tree. The asp fell over the lines, and nearly toppled a nearby power mast.

Figure 3.4: Location 4, beaver

Figure 3.5: The drone

Figure 3.6: Location 4, beaver

Summarized: fallen trees are a common cause of power outages, but can be caused by many different factors. However, wind and inclement weather is the most common cause of fallen trees, even mild winds can be decisive if other conditions increase the risk of trees falling.

The field visit also provided an opportunity to see how a drone pilot operates. He showcased the equipment he uses, and several informal conversations detailing his cooperation with the grid companies were very interesting.

Of note was his experience with grid company systems and the communication flow during his work. He reported that outage incidents were not always reported to the maintenance departments, this could occur when the effort to bring the area back up would fix the underlying issue. This meant that the maintenance department would not receive information regarding potential issues at certain locations. This could be important to better understand the historical data of an area, to better understand the local challenges and potential root causes of incidents. An example of this is beavers, where knowledge about the local beaver population could help predict further incidents in the area.

Figure 3.7: Location 4, beaver

3.2 Visit at a power grid operation center

To gain further insight into how grid companies operate a visit to a grid company was scheduled. There, talks with management and employees in operations, maintenance, and IT were held. In these talks, they spoke about the day to day operations, what tools they use and what challenges the different departments face.

Despite strict access restrictions, I was allowed to visit the operation center and observe grid operators as they worked. The operation center is a restricted area with limited access due to security reasons. For the same reason it was not allowed to take photographs during the visit.

Inside the operation center it was possible to observe how the grid operators work, as well as ask questions. This provided a lot of insight into the challenges that the operators face. The primary task of the operators in the operation center is to quickly bring areas that experience outages back in operation. To localize the cause of the outage, operators start by disconnecting and reconnecting areas around the potential site to determine where the source of the outage stems from. This work will only provide a general location, so inspections are required to accurately find the cause. This work often requires local knowledge of an area, and previous incident history in order to quickly determine the location of the outage.
One of the responses that stood out during the visit was when an operator was asked whether he was aware of known issues

from the maintenance department. He said this information was available in Netbas, but that in a situation with an outage, he could not prioritize looking this information up. «If only I could see that information directly on the map, that would be something!»

Such a solution was proposed in my specialization project, and received positive responses from the operators during user tests. (Jerndahl, 2021) This idea is kept as a possible idea for a holistic solution.

3.3 Interviews

Interviews with maintenance employees and leaders at three different grid companies were conducted in order to better understand the challenges they face. The grid companies varied in size and geographical location, and therefore had different challenges related to climate and maintenance planning. The interviews focused on goal and information requirements rather than technology or system specific displays or task flows, and were unstructured as suggested by Jones & Endsley.(Endsley & Jones, 2012) The results of these interviews form part of the basis for the GDTA.
Some of the findings are highlighted in the next sections.

Communication flow between operations and maintenance
The grid companies had different experiences with regards to communication between operations and maintenance departments. Common for all was that the communication was free flowing, with no overarching system. Both a large and a smaller company reported that the communication between the departments was good. The third company experienced some cases where not all repairs related to outages were registered and reported to the maintenance department. This information is useful to the maintenance department, as it relates to the current state of the power grid, and how the maintenance department should prioritize its resources.

Drone usage experience
One of the grid companies preferred helicopter inspections over drone usage. The last time they actively used drones for maintenance work was two years ago, and dissatisfaction with image quality and battery life led to bad experience and abandoning of drones for maintenance inspections. From their experiences, using helicopters turned out to be cheaper, as they could inspect long distances of lines within a short timespan.

Using drones required frequent moving of the base of operations, as the drones had limited range and battery life.
There have been major improvements in both image quality and battery life of drones in the last two years, and the other two grid companies frequently used drones for inspections. Their experience was the drones were able to get closer to the equipment, and could take close-up images of higher quality. They found that drones were more efficient than inspections on foot, and far safer than traditional inspections where inspectors had to climb poles.

Vegetation
Trees on lines is the most common cause of power outages for these companies. The triggering cause of this is primarily related to poor weather conditions, and repairing the damage caused is often more difficult due to the same weather conditions. It is difficult to predict which trees that can potentially cause issues, and tree clearing must be weighed against both economic and environmental factors.

Aging Equipment
The age of the power grid was mentioned as a major challenge, and estimating the lifetime of equipment and components can be difficult. Large parts of the grid are old, and it is hard to predict when they must be replaced. From a financial perspective it is desirable to replace parts as close as possible to the end-of-life of the component.

D**ifferent Systems**
One of the main challenges mentioned by all companies is displaying the data they already possess in a meaningful manner. The information is separated between different systems, and it can be a challenge to spot relevant correlations. This is supported by previous findings.(Jerndahl, 2021)

Experience-based human knowledge
A common factor for all three grid companies is that many decisions are based on individual experiences and knowledge of singular employees. An example is that when asked how they found the location and cause of an outage, knowledge about former outages in the same area was mentioned as a key factor. This applies to other tasks, and built up knowledge is not registered or made available to other employees. It therefore appeared as if many considerations and decisions were based on individual experiences and knowledge about the grid the employees had accumulated over the years.

Different systems and lack of a unifying system that gathers all relevant information and data, is also supported in previous findings from the specialization project, where operators in the operations center were the user group. Experience-based human knowledge was also a common factor in previous findings from the same project, where seven operators and operation center leaders from another three Norwegian grid companies were interviewed. (Jerndahl, 2021) In conversations with eSmart it was also mentioned that the different grid companies use different names and symbols for the same elements. This is a major challenge that further complicates the work of designing a holistic solution.

Figure 3.8: Most common cause.
Photo: Magne Kaspersen, Skogrone

3.4 Design Workshops

Creative design workshops were a valuable tool in understanding the challenges faced by grid companies. The goal of the workshops was to introduce creative design processes to representatives from the grid companies in order to learn more about their needs and how to solve them. These representatives were grid company employees that also make up parts of the user group, making them ideal participants.

Due to the COVID-19 pandemic and logistical challenges, the workshops were held digitally. This was a new experience, and it became clear that there are both advantages and disadvantages to holding workshops digitally. The benefit was that it was easy to gather all the involved parties of the GV5D project, which meant that a wide range of different Norwegian grid companies were represented. Learning how to use the digital tools that made digital workshops possible was also a great learning experience. The tools used were Microsoft Teams and Figjam which proved to be a well suited toolsuite for the workshops.

3.4.1 Workshop 0

As holding digital workshops was a new experience, a test workshop was held in advance to ensure that the setup and tools were working as planned. This workshop provided a lot of valuable feedback beyond just verifying the tools and setup. Some of the exercises planned for workshop 1 were also tested, and provided valuable insight for the project.

Participants: Employees from eSmart Systems/Verico
Duration: 1,5 hour
Where: Teams
Tools: Figma FigJam

Goals
Test tools for remote workshops. Gain insights, brainstorm ideas and discuss solutions.

Agenda
- Intro (10 min)
- Icebreaker (10 min)
- Persona (15 min)
- User needs (20 min)
- Post-up brainstorming (20 min)
- Debrief
- Feedback

The workshop started with an introduction to user-centered design, and why design workshops can be useful. This was probably the first creative design workshop for most of the participants, and to motivate them and reduce skepticism, a short description of what design can mean in safety critical systems was shown.

To get the participants “on board”, relax and get into a creative mood, the session started with an ice-breaker exercise:

“If power poles were an animal, what animal would it be? Draw this animal in 30 seconds.”

Woodpeckers, mooses and giraffes were drawn with various degree of success and accompanying laughter. The artists were then ready for the more serious exercises.

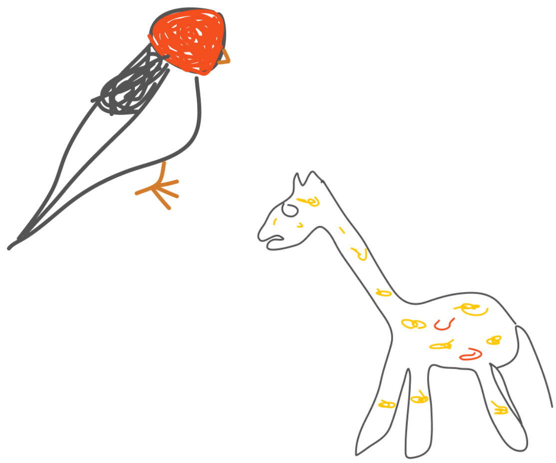


Figure 3.9: Ice breaker

The persona exercise was done in plenum and made way for interesting discussions. They decided to place the persona in the future, and described a new kind of maintenance worker that doesn't exist today. Meet Geir Hansen:

Age: 56
Occupation: Maintenance worker
Education: Electrical engineer
Devices: Desktop

Bio:
Geir enjoys the outdoor life, and has previously worked as a lineworker. He is the maintenance worker of the future, and has a high understanding of technology. He has grown up playing video games and is a highly proficient computer user.

Goals:
Correctly sort the priority of maintenance tasks and prevent outages.

Pain points:
Low maintenance budget
He is unable to do the desired maintenance work because the line segment cannot be disconnected. This leads to repeated discussions with other roles.
It is difficult to do the right prioritization because the needed information is not provided.

Information needs:
-technical documentation
-state of the grid
-fauna

Challenges and user needs:

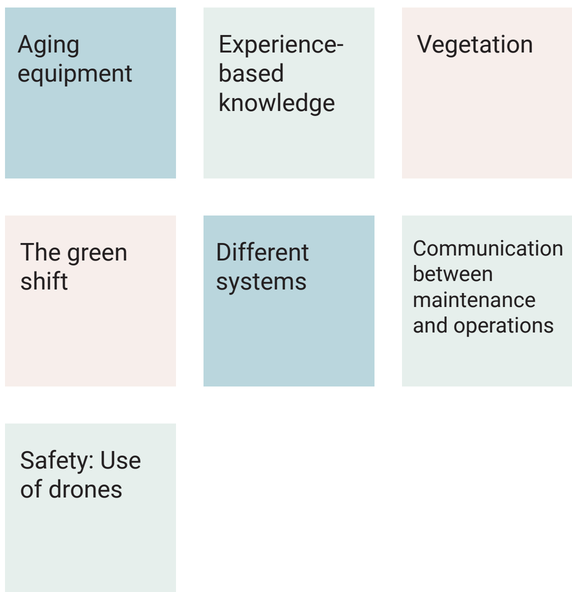


Figure 3.10: Challenges and needs

Post-up brainstorming

This exercise provided useful comments for both the concept work and the prototyping. Documenting historical data, visual representation of the state of the grid, and improved communication capabilities between employees and departments were all mentioned as possible points of interest. See appendix A for complete results.

Thoughts
The ice breaker exercise proved very successful in increasing the engagement level of the particiants, and I believe it was an important factor for the results in the upcoming exercises.

In the exercise about challenges and user needs, the age of the power grid received more votes than vegetation, despite vegetation being the major cause of outages (see section 2.1.6). This could be related to the workshop participants not being members of the user group, but specialists working with analysis and inspection of equipment that are not intimately familiar with vegetation management. Another possible cause is that they misjudge the ability for the maintenance departments to influence vegetation outages, while the replacing components is something they know the maintenance department often handles. It could also be that participants influenced each other's voting by voting for the initially most popular option.

Experience based knowledge was the clear winner in the vote, and this matches the responses from the interviews. The issue of information being shared across multiple systems only received 1 vote, despite this being mentioned as a primary challenge in all the conducted interviews.

3.4.2 Workshop 1

At Workshop 1 (WS1) participants from nine different grid companies that all represented the user group were present. In addition, some employees from eSmart/Verico participated. There were a total of 20 participants on teams, of which 13 were actively participating in exercise. In this workshop it was decided to divide the participants into two groups during some of the exercises

Participants: Representatives from nine different grid companies, employees from eSmart/Verico
Duration: 2 hours
Where: Teams
Tools: Figma FigJam

Goals
Gain insights and get to know the user and the user's needs and challenges. Brainstorm ideas and discuss solutions.

Agenda

Intro (15 min)
Icebreaker (10 min)
User needs (20 min)
Persona (30 min)
Post-up brainstorming (30 min)
Debrief
Feedback

Results
WS1 started with the same icebreaker as in WS0. In addition to the animals, the participants were challenged to draw the greatest enemy of the power grid.
Horses, lions and giraffes were accompanied by lightning, falling trees and broken power lines.

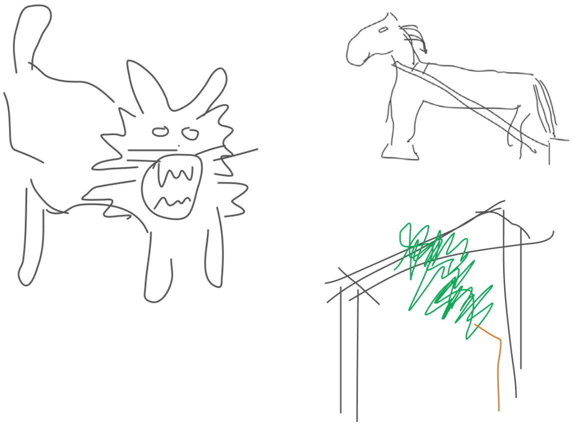


Figure 3.11: Ice breaker WS1

User needs and challenges were discussed and voted on among the participants, before dividing the participants into groups. The following exercise resulted in two different personas, which will be presented in chapter 6.

The brainstorming session provided more useful ideas and considerations. See appendix B for complete results.

Thoughts

Brainstorming and discussions with representatives of the user group proved to be very valuable. Throughout the session it became even clearer that different grid companies have different challenges and needs. As the grid companies present were all of different sizes and from different geographical regions, this result highlights the variance in Norwegian power grid companies.

The exercise where the participants vote on the most important issues may not be representative. The participants quickly notice how the voting proceeds, and can be swayed to vote on the same issues. It became clear that some of the issues that received no votes were still mentioned as big challenges in the interviews.
It also seemed as if the association with the GV5D influenced some of the votes, as the votes often matched the expressed goal of the GV5D project. Still, the issues that received the most votes were all issues of great importance, and the GV5D project is based on eSmart Systems experience in developing systems to solve the challenges of the grid companies.

3.4.3 Concept idea outline

After the first workshop with the grid companies associated with GV5D, the acquired insight so far was used in a brainstorming session around a possible concept.

Some of the discovered issues that were given a high priority was the so-called experience based knowledge, as in the knowledge that grid company employees build up through experience, and that is not necessarily written down or made available to other employees. In addition, the positiblity of discussing issues or discoveries and improving communication was also chosen as an area to be futher explored. In essence, the responsibility of the maintenance department is to maintain the grid and prevent outages, while the operation center is responsible for restoring power after outages.

Maintenance Center

The idea is that it would be beneficial to create a maintenance center. This would make the task of predicting and preventing outages easier, by improving the SA of the maintenance workers. The proposed maintenance center will gather all relevant information relevant to maintenance and use large central screens to display an overview of this information.
In a maintenance center the maintenance employees can discuss and analyze specific findings together, as well as help each other make decisions. By sharing knowledge and experience in such a setting, the risk of individual misjudgements can be decreased, and the knowledge sharing between employees will increase.

Further thoughts are that employees will have workstations like an operation center. Here the different roles can have their own workstations with a similar two-screen solution to the primary screens. Information layers should be adapted to each employee's role and their needs, and should show more detailed information relevant to their role.

Maintenance center

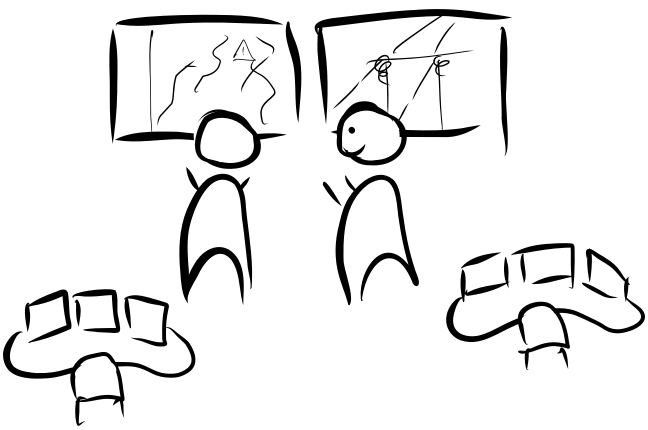


Figure 3.12: Concept idea

3.4.4 Workshop 2

The results from WS1 were processed and sorted before WS2. Due to limited time in the remote workshops, some exercises that normally would have been part of a design workshop were done in advance of WS2.

- Affinity diagramming was done to cluster the user needs and observations presented in WS1, together with the thoughts and ideas from the post-up session. These post-its were meaningfully clustered in categories.
- A concept idea was outlined based on the findings from the research phase, as explained further in the previous section.

Participants: Same as WS1
Duration: 2 hours
Where: Teams
Tools: Figma FigJam

Goals
Discuss insights and results from WS1. Present suggested concept outline and get feedback.
Ideate possible solutions through user scenarios and prototype exercises.

Agenda
Intro (15 min)
Icebreaker (10 min)
Retrospective (20 min)
Post-up and votes (20 min)
Pause (10 min)
Present concept outline (10 min)
Feedback concept (20 min)
User scenario (30 min)
Prototyping (30 min)
Pause (10 min)
Debrief and feedback (30 min)

Results

This WS initiated valuable discussions when presenting the personas and post-up results from WS1.

It was also of great value to get feedback on the suggested concept outline through a feedback exercise. The participants were positive about the idea of gathering all relevant information in one system, and that it would be easier to get an overview in a map view. They emphasized that it would be easier to get a full overview of all parts of the grid. Their concern was that it would require more resources if they had to put more employees in such a future maintenance center. It was also mentioned that they wanted a product that did not require a powerful maintenance center to be established.
They also came up with more ideas for such a concept, for example use of augmented reality (AR) and autonomous drone inspections.

In the scenario session, one group sketched a long-term scenario, while the other group sketched out a concrete situation from a normal day at work. These different approaches were not planned, but resulted in varied and useful discussions. The prototyping session resulted in some concrete suggestions on information requirements, for example the ability to compare a drone image with a previous image to clearly see the development of a fault. See appendix C for complete results.

Thoughts

Through discussions and exercises in WS1 and WS2 it became clear that the different grid companies operate in different ways. They also differed in how they used existing systems from eSmart and Verico. Since the challenges they faced based on size and geography varied, so did their chosen tools and solutions. Some companies have issues with large grid sections that suffer from aging, and the different climates around the country provide different challenges. It was beneficial to explore different scenarios with the participants, where they contributed with realistic scenarios and challenges that they face in their work.

In the feedback session at the end of the WS, the participants expressed that it was engaging to use Figma, and that it was useful to share experiences across companies. It was also mentioned that the task and the goal were not clear enough, and there was uncertainty as to whether it was intended as a solution that is possible today or a solution for the future. This may be an indication that the scope should be further defined.

3.5 Tech-oriented workshops and user forum

As a part of the GV5D project, several technology oriented workshops were held by eSmart Systems. Observing these workshops provided increased insight into the domain, in addition the workshops showcased the new opportunities provided by new advanced technology. The workshops also allowed the grid companies to present their thoughts and challenges from their own point of view, and this was valuable insight for the project. To increase involvement from the representatives of the grid companies, discussions and questionnaires were used. This information was utilized to determine if the suggested solutions in GV5D matched the needs of the users.

Despite eSmart often being technology driven in their projects, these types of workshops are an important tool in the Situation Awareness Oriented Design (SAOD) process. These technology workshops, and user forums, that explore the technological possibilities can be considered as technology analysis: the second important contribution to the design process. This is often conducted simultaneously with the GDTA, as well as determining the range of devices, for instance sensors, and their characteristics that are available for gathering and displaying the SA requirements detected in the GDTA. (Endsley and Jones). Many companies have internal research and development programs to actively develop new technological capabilities, and this is one of eSmart's strengths, as they have a strong focus on research and development.

The following sections will highlight some of the technologies that are being developed. The information in 3.5.1-3.5.3 is gathered from internal presentations from user forums and workshops with eSmart Systems.

3.5.1 IR sensors

An ongoing research project is how IR-sensors can aid in discovering faults or issues in components of the above ground power grid. IR sensors measure radiation in infrared wavelengths, and convert this energy to an electric signal that is translated into an image. The intensity of the IR signal is related to the temperature of the component. The signal reaching the IR sensor depends on several factors. The material properties of the component, such as absorption, and heat conductivity play a role. In addition, the atmospheric properties of the air between the sensor and the component matter. Humidity and temperature can impact the measurements, as the air absorbs emitted energy from the object, while sunshine will affect the measurements by heating everything, making the differences in temperature appear smaller. Measurements should therefore be taken when there is no sun, rain, snow or high dust concentration.

IR-sensors can help detect issues in components, as many components heat up before failing. Early detection of failing components can therefore prevent outages.

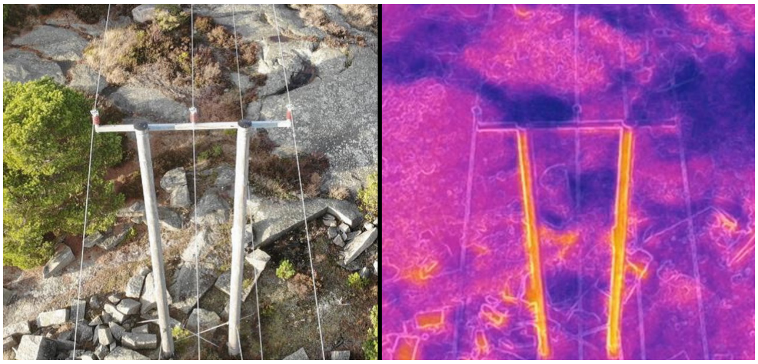


Figure 3.13: IR sensors. Photo: eSmart Systems

3.5.2 LiDAR classification

LiDAR stands for Light Detection and Ranging, and is a remote sensing method that measures ranges using light in the form of a pulsed laser. This can be used to create a three dimensional representation of the surface, visualized as a point cloud. Lidar classification can specify which object a point consists of, for example ground, low vegetation, high vegetation, power grid lines, power masts etc. This is mainly done manually today, which is a time-consuming process.

The goal is to make this process automatic, to save time and create models that are trained on power-grid-specific data. A challenge is to get satisfactory quality of the database. Lidar classification is also explored in the SkogRiskAI project, and the goal is to be able to detect height, distance and angle of the vegetation in relation to the power lines.

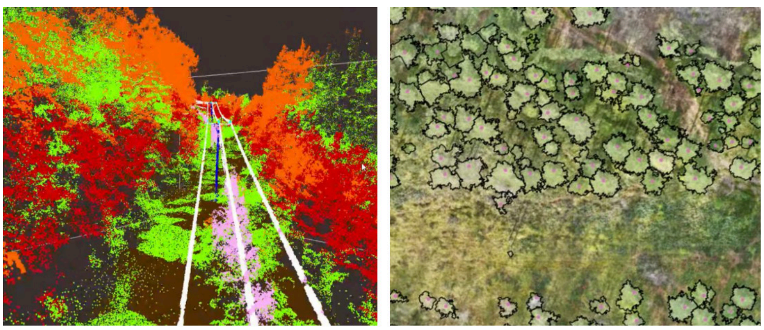


Figure 3.14: LiDAR classification. Photo: eSmart Systems

3.5.3 Game technology

In collaboration with Nordic Media Lab, eSmart Systems will explore how gaming technology can potentially provide better insight and decision support for grid companies. Using game technology, the power grid and its surroundings can be rendered visually in a 3D view.

Figure 3.15: Game technology. Photo: eSmart Systems

4

Goal Directed Task Analysis

Goal Directed Task Analysis

The GDTA provided a vital structure and great assistance in the development of the concept and prototype. It was a dynamic process, and the GDTA changed several times due to new information during the process.

4.1 About GDTA

Before designing the system, it is important to understand what supporting SA means in power grid monitoring and maintenance work. A cognitive task analysis, called the goal directed task analysis, is a helpful tool in gaining this understanding. The GDTA focuses on information that changes dynamically rather than focusing on general system knowledge. These dynamic information needs are what is called the SA requirements. In the GDTA the focus is on what information is needed to support SA, and what the operator ideally need to know to meet each goal. By focusing on what information is needed rather than what's available in the current system, it is easier to better understand what is needed to support good SA.(Endsley & Jones, 2012)

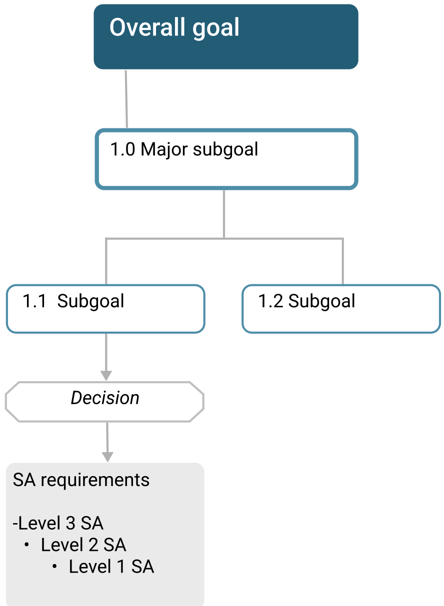
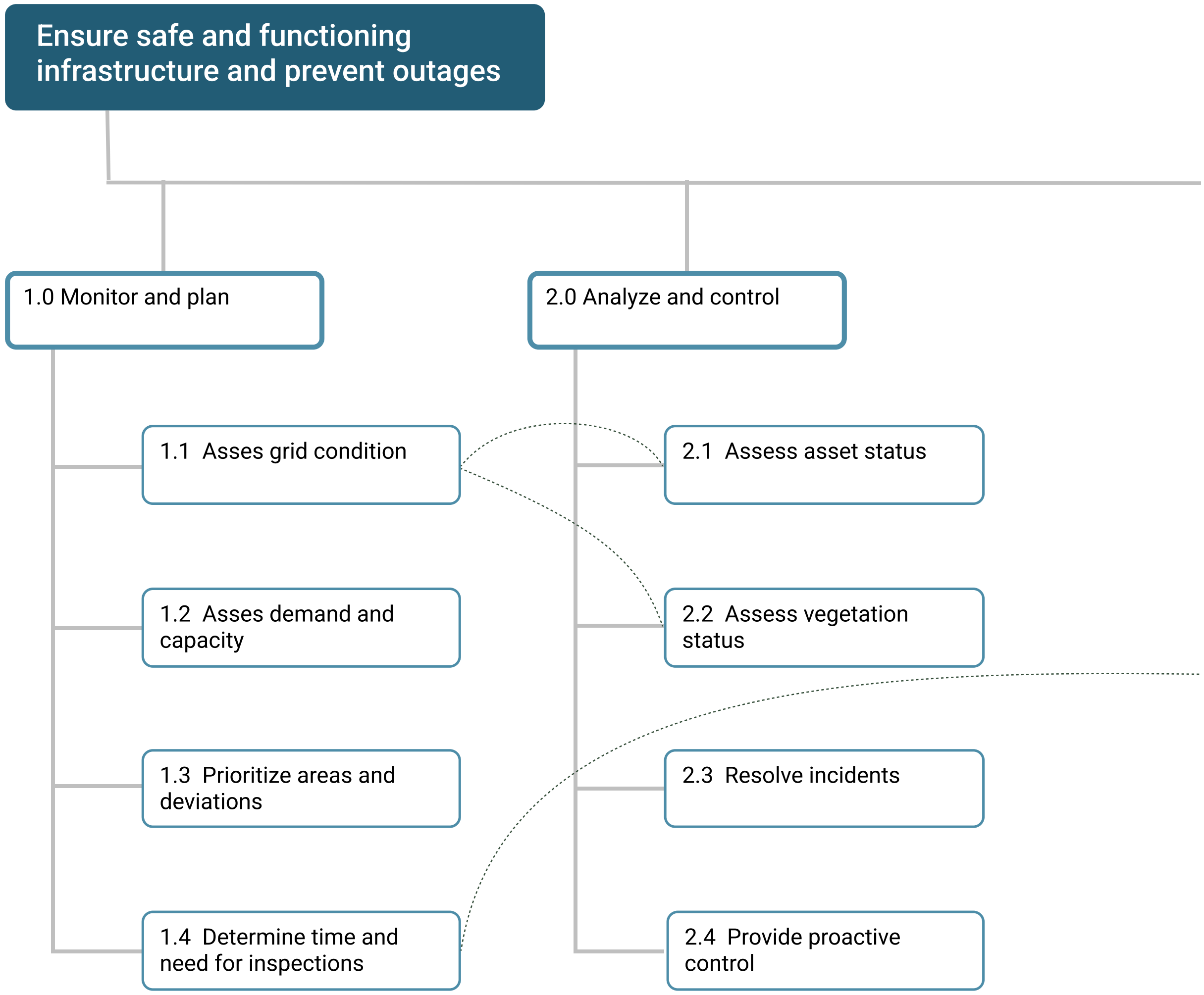


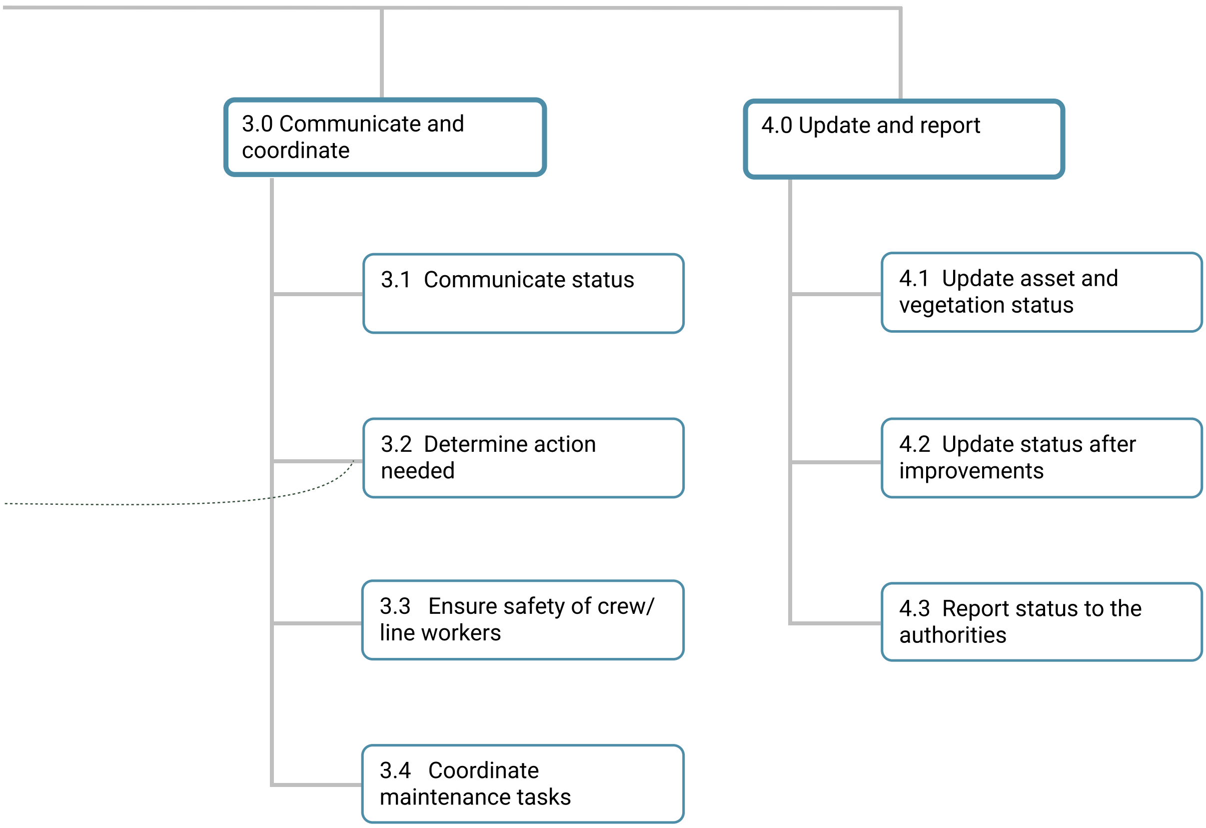
Figure 4.1: GDTA structure. (Endsley & Jones, 2012)

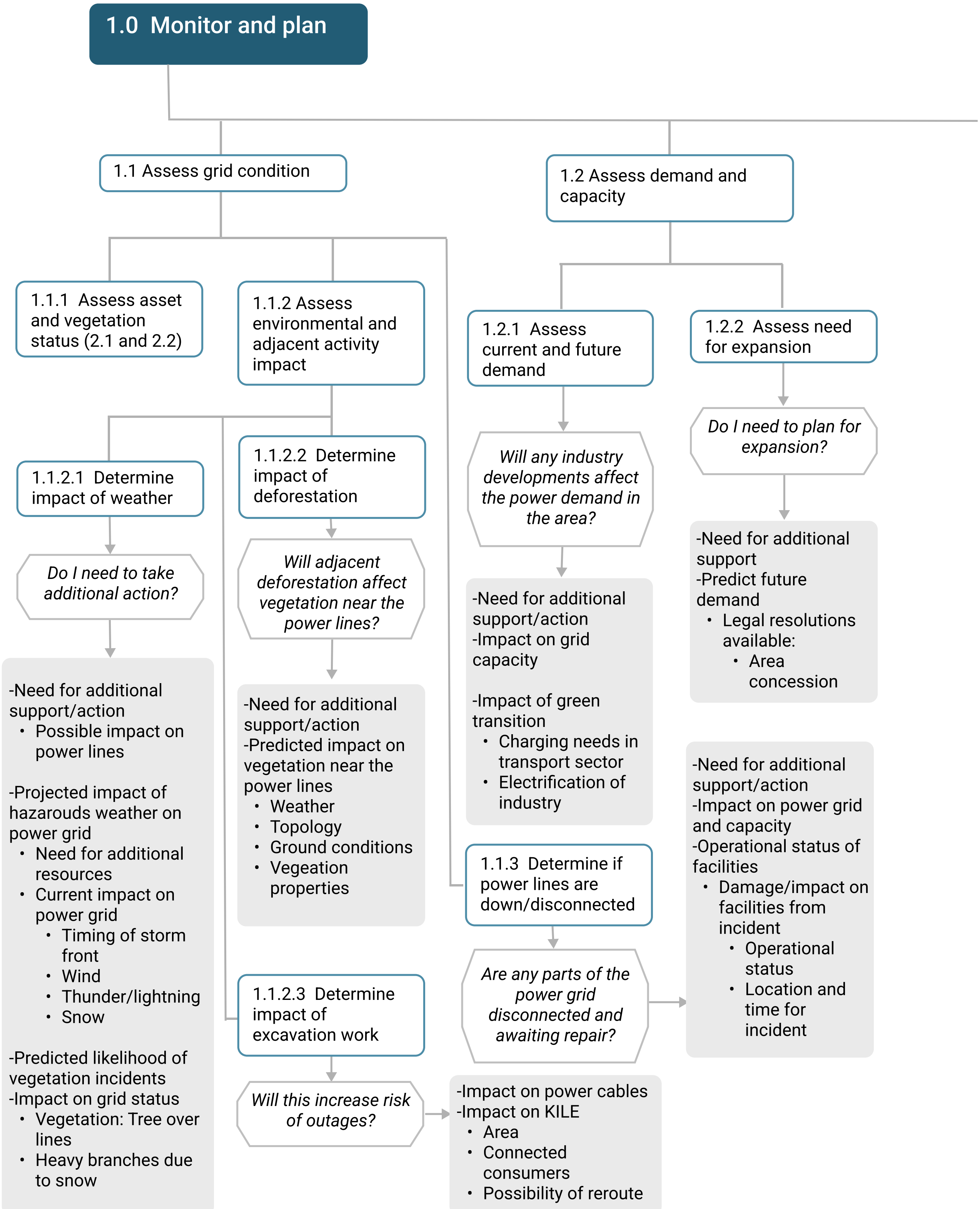
4.2 Determining SA requirements

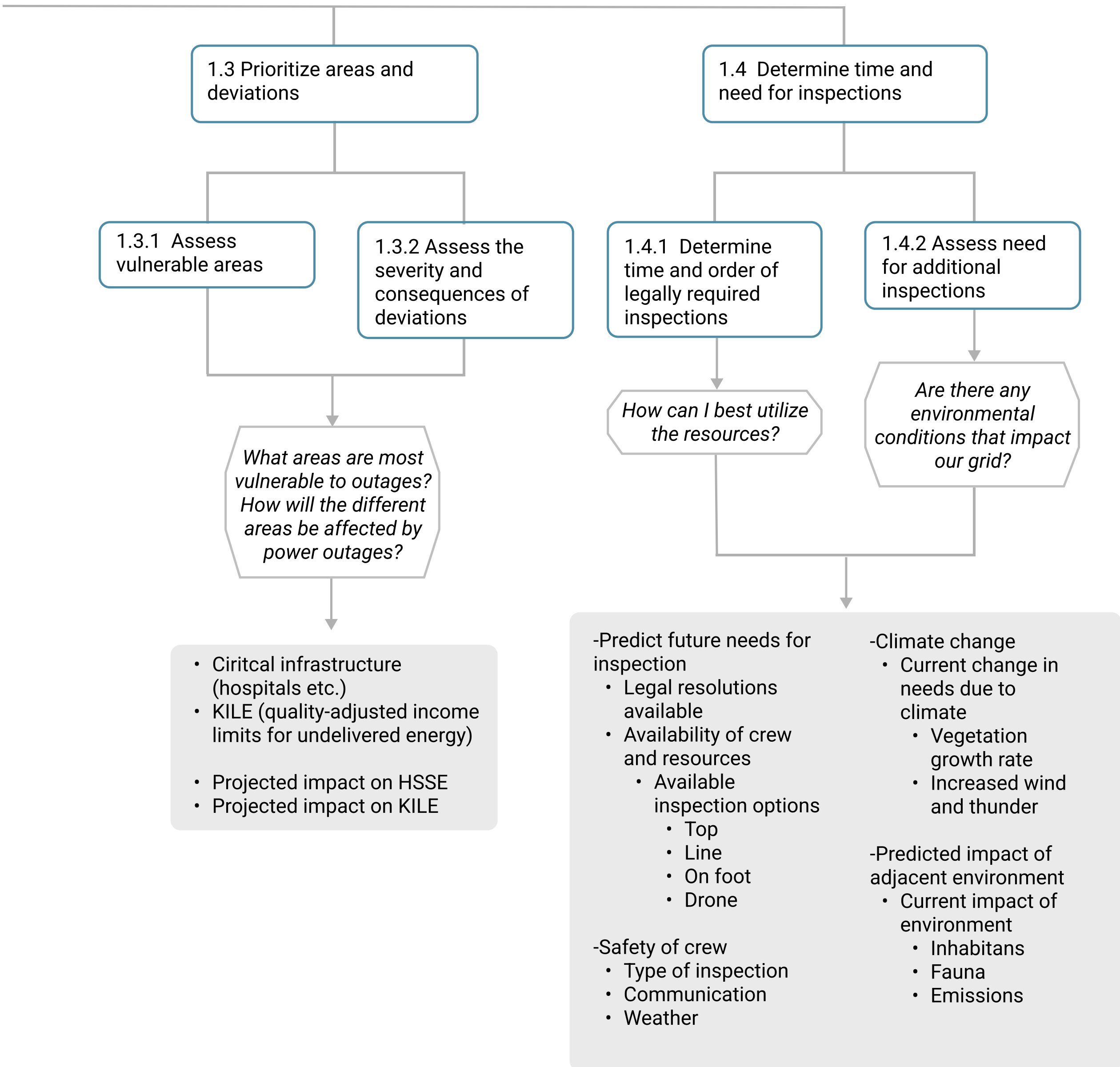
Based on the interviews, workshops, talks and previous insight from literature review and interviews, the GDTA was done to get a clear understanding of the goals of a maintenance worker in a power grid company.
The Goal Directed Task Analysis has been a continuous and time consuming process. Despite being quite time consuming, the method has been a very useful tool both for understanding the domain, as well as the needs of the users. The analysis work has been of great importance developing a conceptual prototype that can aid the user in their tasks.

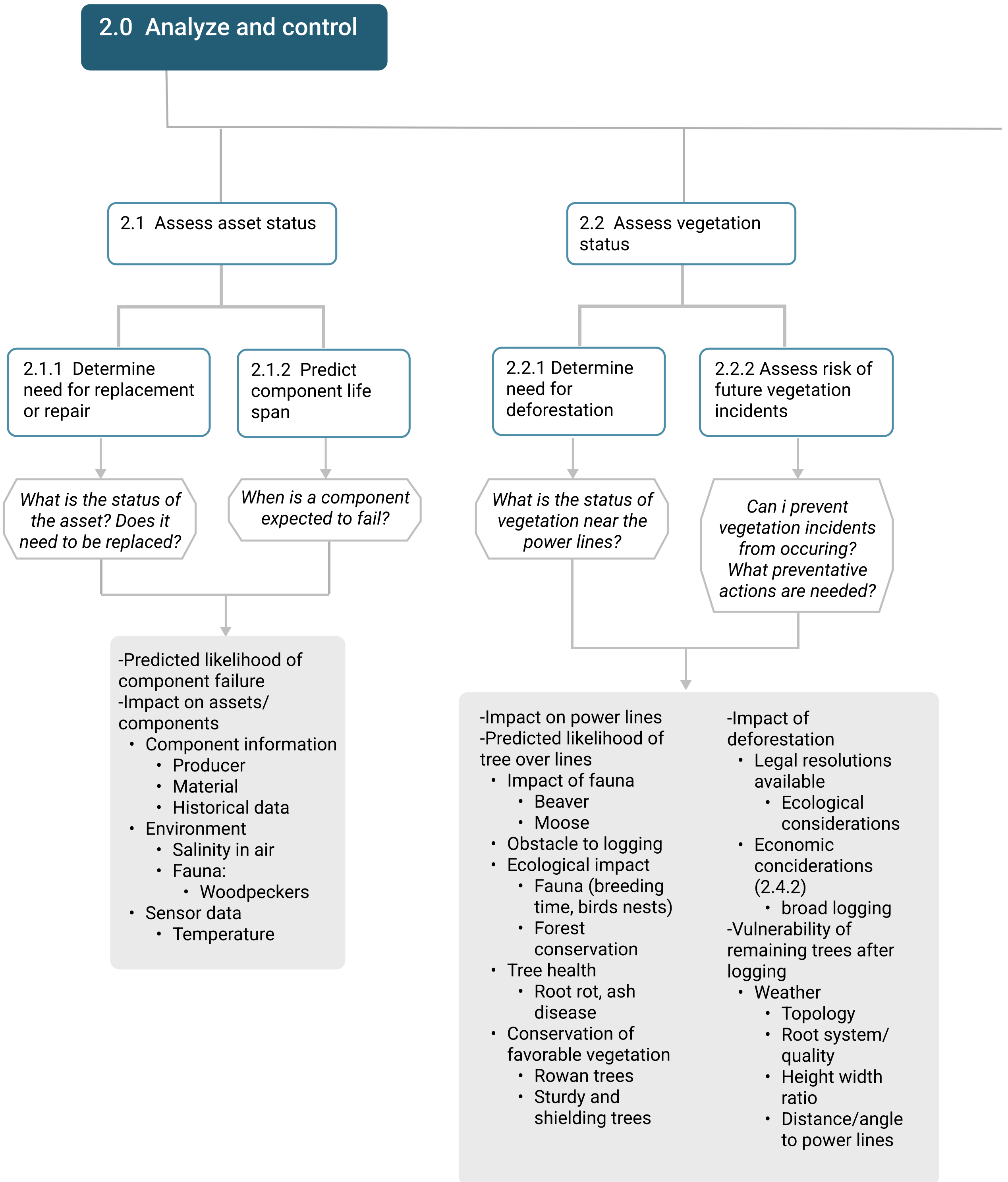
The basis for the GDTA is the maintenance department in a power grid company. As the size and responsibilities of the maintenance departments greatly vary between different power grid companies, this GDTA will not suit all maintenance employees in a power grid company. The intention of this GDTA was to take a wide approach, and attempt to analyze the general goals, tasks, challenges and information requirements of a maintenance department. Due to the wide scope, the GDTA will be best suited for a maintenance employee in a small power grid company, where each employee is responsible for a wide range of tasks. In Norway, these companies are common, and small power grid companies may have as few as 1-2 employees dedicated to maintenance. In large companies each employee may oversee different areas of maintenance, such as planning, inspections, vegetation control and equipment management.
In smaller companies these responsibilities are often shared between just a few people.

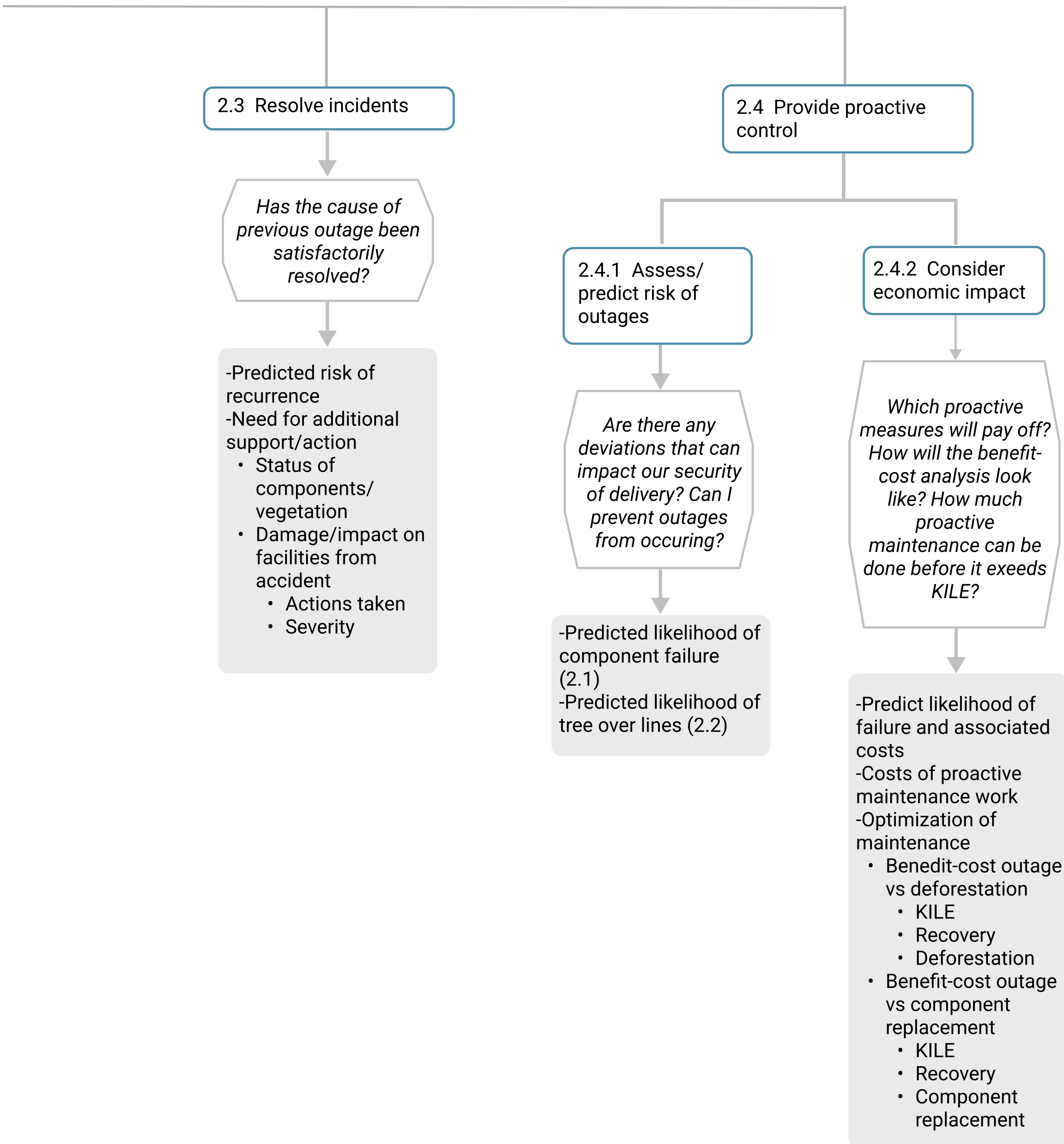

Ensure safe and functioning infrastructure and prevent outages
1.0 Monitor and plan
2.0 Analyze and control
1.1 Asses grid condition
2.1 Assess asset status
1.2 Asses demand and capacity
2.2 Assess vegetation status
1.3 Prioritize areas and deviations
2.3 Resolve incidents
1.4 Determine time and need for inspections
2.4 Provide proactive control

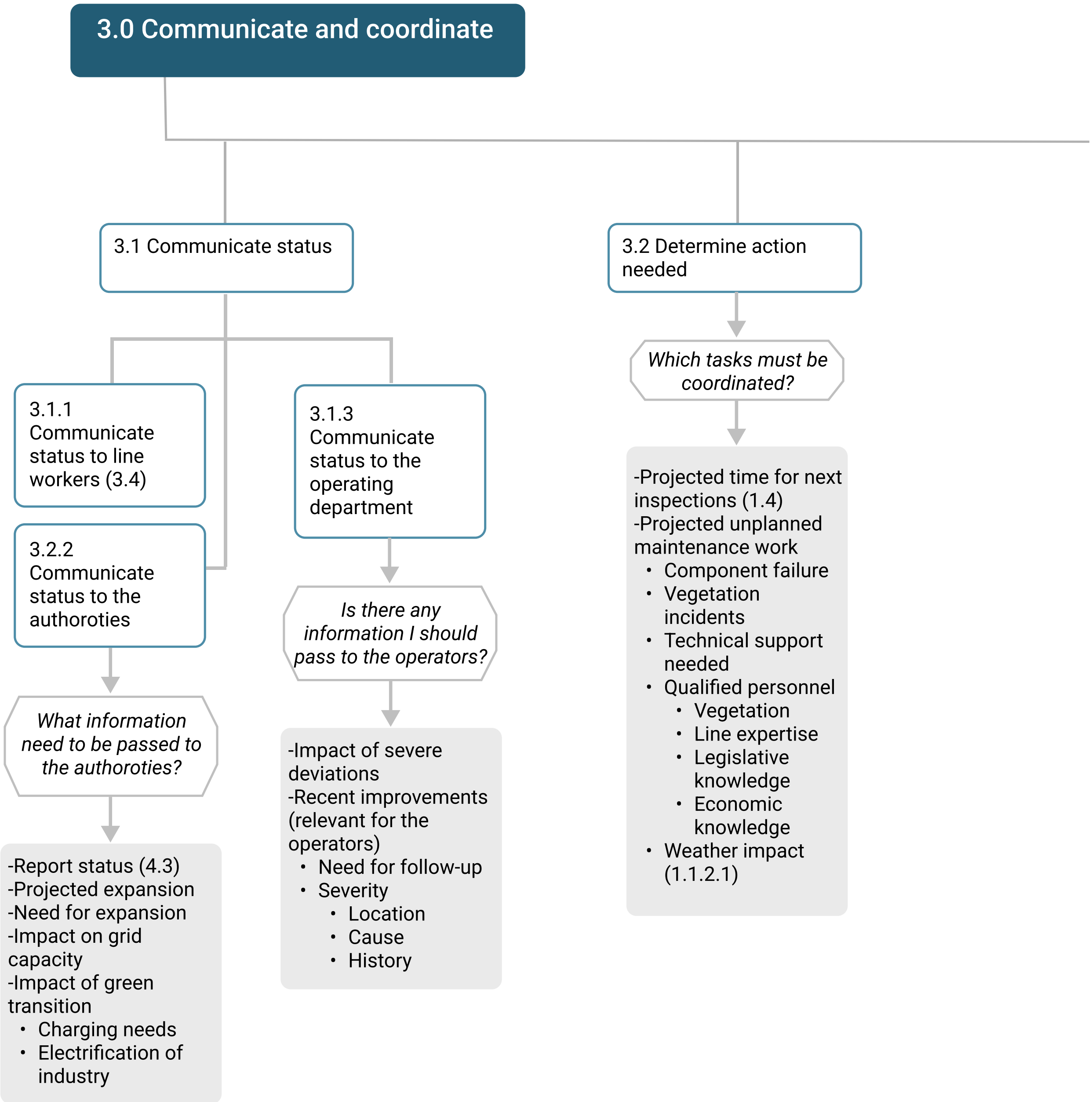

3.0 Communicate and coordinate
3.1 Communicate status
3.2 Determine action needed
3.3 Ensure safety of crew/ line workers
3.4 Coordinate maintenance tasks
4.0 Update and report
4.1 Update asset and vegetation status
4.2 Update status after improvements
4.3 Report status to the authorities

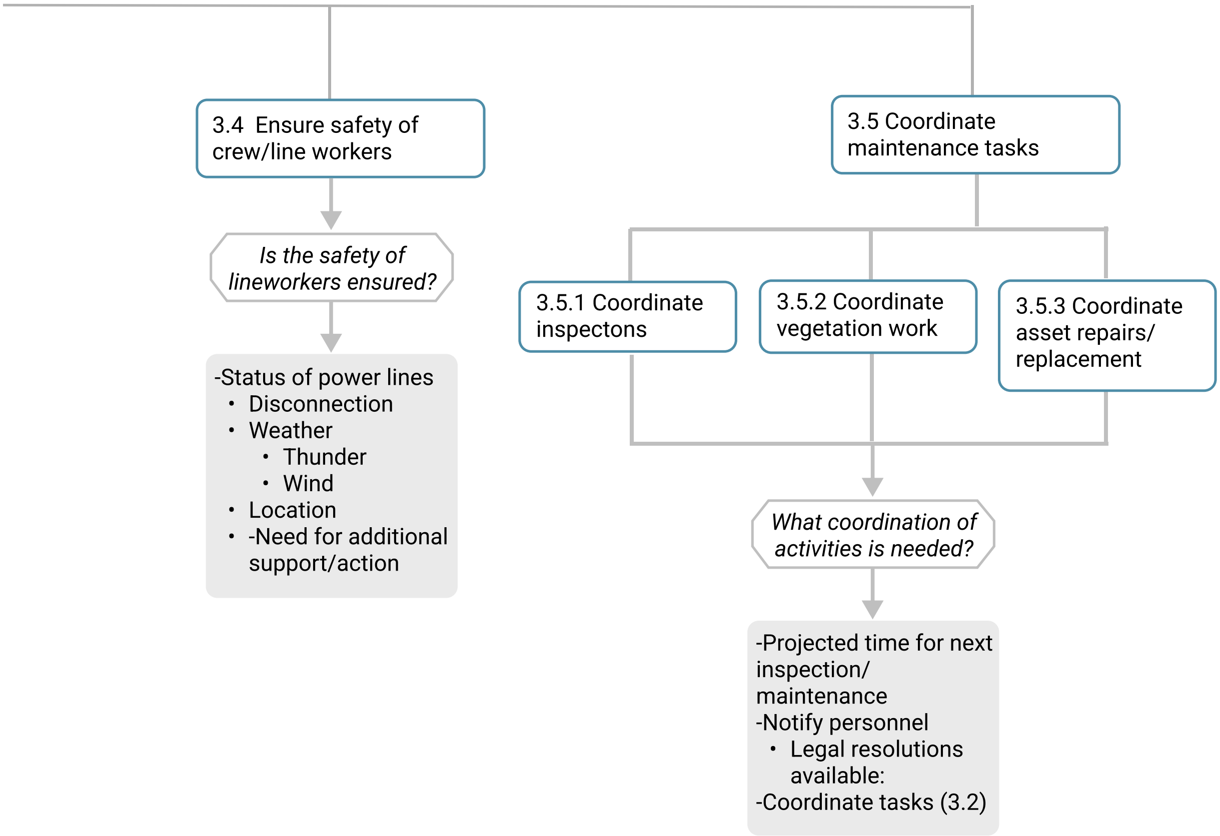

1.0 Monitor and plan
1.1 Assess grid condition
1.2 Assess demand and capacity
1.1.1 Assess asset and vegetation status (2.1 and 2.2)
1.1.2 Assess environmental and adjacent activity impact
1.2.1 Assess current and future demand
1.2.2 Assess need for expansion
1.1.2.1 Determine impact of weather
1.1.2.2 Determine impact of deforestation
Will any industry developments affect the power demand in the area?
Do I need to plan for expansion?
Do I need to take additional action?
Will adjacent deforestation affect vegetation near the power lines?
-Need for additional support -Predict future demand • Legal resolutions available: • Area concession
-Need for additional support/action -Impact on grid capacity -Impact of green transition • Charging needs in transport sector • Electrification of industry
-Need for additional support/action • Possible impact on power lines -Projected impact of hazarouds weather on power grid • Need for additional resources • Current impact on power grid • Timing of storm front • Wind • Thunder/lightning • Snow -Predicted likelihood of vegetation incidents -Impact on grid status • Vegetation: Tree over lines • Heavy branches due to snow
-Need for additional support/action -Predicted impact on vegetation near the power lines • Weather • Topology • Ground conditions • Vegeation properties
-Need for additional support/action -Impact on power grid and capacity -Operational status of facilities • Damage/impact on facilities from incident • Operational status • Location and time for incident
1.1.3 Determine if power lines are down/disconnected
Are any parts of the power grid disconnected and awaiting repair?
1.1.2.3 Determine impact of excavation work
Will this increase risk of outages?
-Impact on power cables -Impact on KILE • Area • Connected consumers • Possibility of reroute


1.3 Prioritize areas and deviations
1.4 Determine time and need for inspections
1.3.1 Assess vulnerable areas
1.3.2 Assess the severity and consequences of deviations
1.4.1 Determine time and order of legally required inspections
1.4.2 Assess need for additional inspections
How can I best utilize the resources?
Are there any environmental conditions that impact our grid?
What areas are most vulnerable to outages? How will the different areas be affected by power outages?
• Ciritcal infrastructure (hospitals etc.)
• KILE (quality-adjusted income limits for undelivered energy)
• Projected impact on HSSE
• Projected impact on KILE
-Predict future needs for inspection
• Legal resolutions available
• Availability of crew and resources
• Available inspection options
• Top
• Line
• On foot
• Drone
-Safety of crew
• Type of inspection
• Communication
• Weather
-Climate change
• Current change in needs due to climate
• Vegetation growth rate
• Increased wind and thunder
-Predicted impact of adjacent environment
• Current impact of environment
• Inhabitans
• Fauna
• Emissions

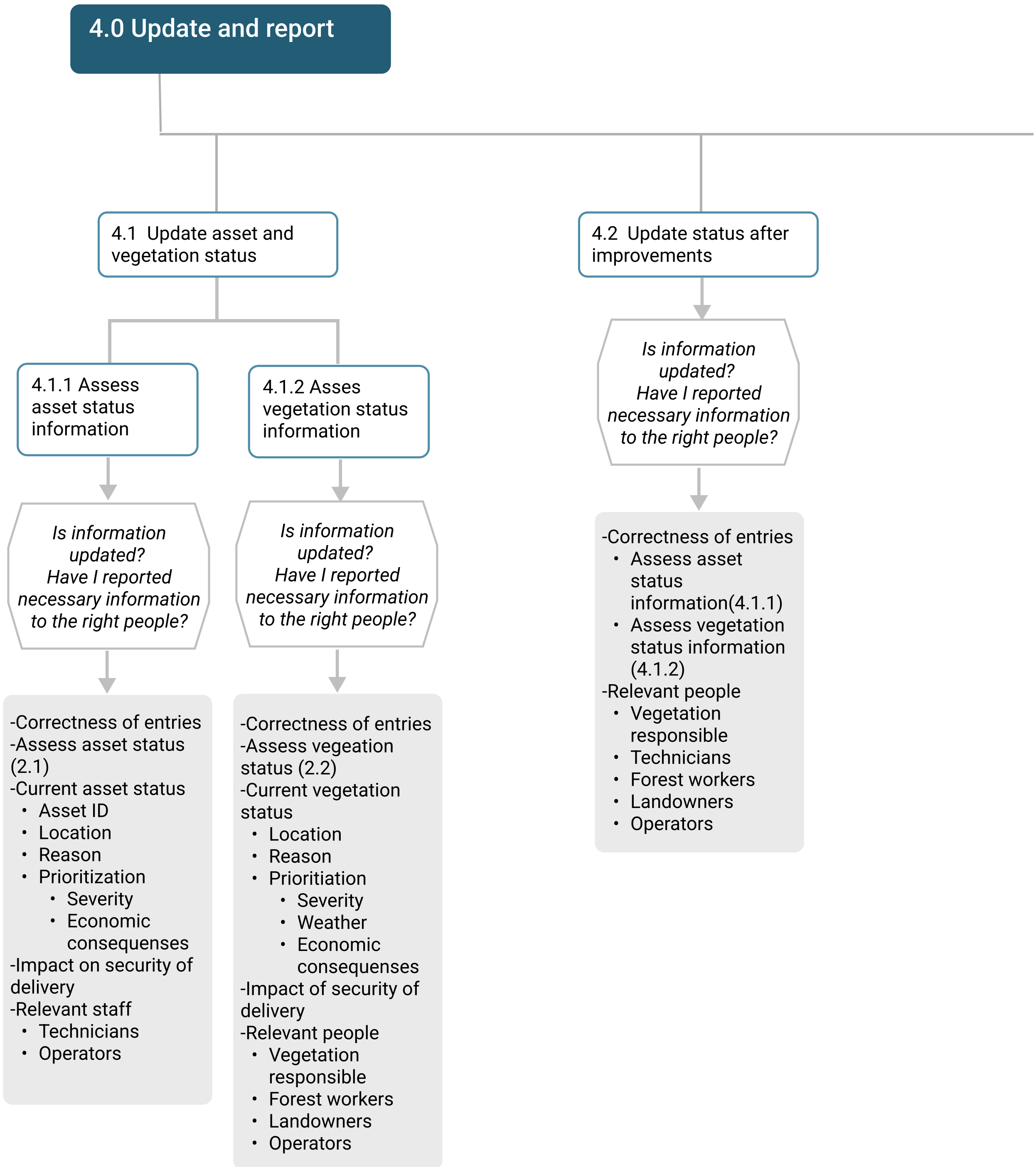

2.0 Analyze and control
2.1 Assess asset status
2.2 Assess vegetation status
2.1.1 Determine need for replacement or repair
2.1.2 Predict component life span
2.2.1 Determine need for deforestation
2.2.2 Assess risk of future vegetation incidents
What is the status of the asset? Does it need to be replaced?
When is a component expected to fail?
What is the status of vegetation near the power lines?
Can i prevent vegetation incidents from occuring? What preventative actions are needed?
-Predicted likelihood of component failure
-Impact on assets/ components
• Component information
• Producer
• Material
• Historical data
• Environment
• Salinity in air
• Fauna:
• Woodpeckers
• Sensor data
• Temperature
-Impact on power lines
-Predicted likelihood of tree over lines
• Impact of fauna
• Beaver
• Moose
• Obstacle to logging
• Ecological impact
• Fauna (breeding time, birds nests)
• Forest conservation
• Tree health
• Root rot, ash disease
• Conservation of favorable vegetation
• Rowan trees
• Sturdy and shielding trees
-Impact of deforestation
• Legal resolutions available
• Ecological considerations
• Economic concidерations (2.4.2)
• broad logging
-Vulnerability of remaining trees after logging
• Weather
• Topology
• Root system/ quality
• Height width ratio
• Distance/angle to power lines

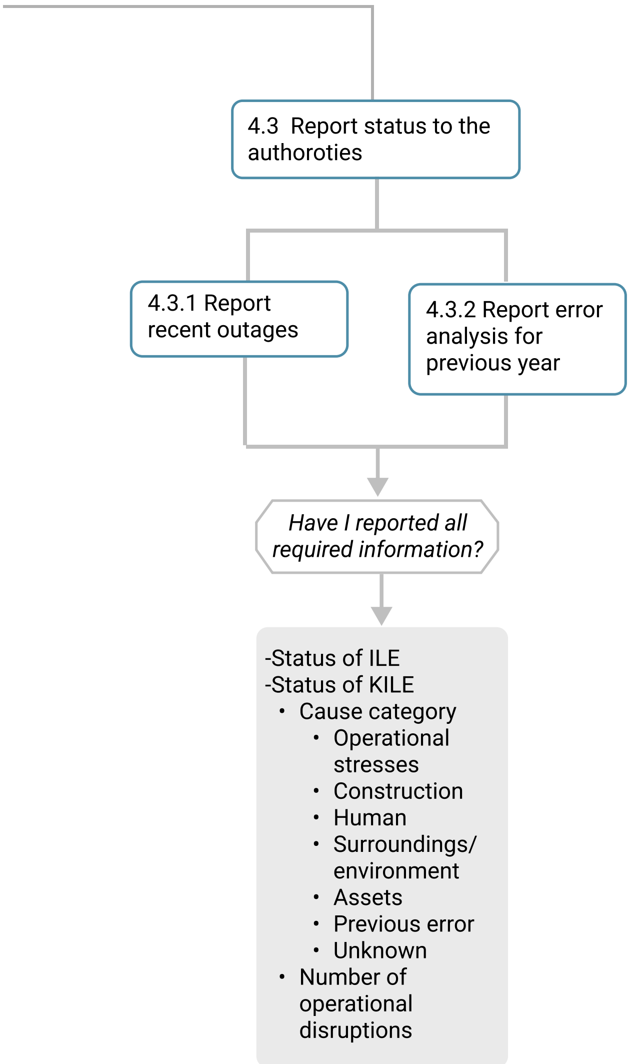

2.3 Resolve incidents
Has the cause of previous outage been satisfactorily resolved?
-Predicted risk of recurrence
-Need for additional support/action
• Status of components/ vegetation
• Damage/impact on facilities from accident
• Actions taken
• Severity
2.4 Provide proactive control
2.4.1 Assess/ predict risk of outages
Are there any deviations that can impact our security of delivery? Can I prevent outages from occuring?
-Predicted likelihood of component failure (2.1)
-Predicted likelihood of tree over lines (2.2)
2.4.2 Consider economic impact
Which proactive measures will pay off? How will the benefit-cost analysis look like? How much proactive maintenance can be done before it exeeds KILE?
-Predict likelihood of failure and associated costs
-Costs of proactive maintenance work
-Optimization of maintenance
• Benedit-cost outage vs deforestation
• KILE
• Recovery
• Deforestation
• Benefit-cost outage vs component replacement
• KILE
• Recovery
• Component replacement


3.0 Communicate and coordinate
3.1 Communicate status
3.1.1 Communicate status to line workers (3.4)
3.2.2 Communicate status to the authoroties
What information need to be passed to the authoroties?
-Report status (4.3)
-Projected expansion
-Need for expansion
-Impact on grid capacity
-Impact of green transition
• Charging needs
• Electrification of industry
3.1.3 Communicate status to the operating department
Is there any information I should pass to the operators?
-Impact of severe deviations
-Recent improvements (relevant for the operators)
• Need for follow-up
• Severity
• Location
• Cause
• History
3.2 Determine action needed
Which tasks must be coordinated?
-Projected time for next inspections (1.4)
-Projected unplanned maintenance work
• Component failure
• Vegetation incidents
• Technical support needed
• Qualified personnel
• Vegetation
• Line expertise
• Legislative knowledge
• Economic knowledge
• Weather impact (1.1.2.1)



3.4 Ensure safety of crew/line workers
Is the safety of lineworkers ensured?
-Status of power lines
• Disconnection
• Weather
• Thunder
• Wind
• Location
• -Need for additional support/action
3.5 Coordinate maintenance tasks
3.5.1 Coordinate inspectons
3.5.2 Coordinate vegetation work
3.5.3 Coordinate asset repairs/ replacement
What coordination of activities is needed?
-Projected time for next inspection/ maintenance
-Notify personnel
• Legal resolutions available:
-Coordinate tasks (3.2)


4.0 Update and report
4.1 Update asset and vegetation status
4.2 Update status after improvements
4.1.1 Assess asset status information
4.1.2 Asses vegetation status information
Is information updated? Have I reported necessary information to the right people?
-Correctness of entries
-Assess asset status (2.1)
-Current asset status
• Asset ID
• Location
• Reason
• Prioritization
• Severity
• Economic consequenses
-Impact on security of delivery
-Relevant staff
• Technicians
• Operators
Is information updated? Have I reported necessary information to the right people?
-Correctness of entries
-Assess vegeation status (2.2)
-Current vegetation status
• Location
• Reason
• Prioritiation
• Severity
• Weather
• Economic consequenses
-Impact of security of delivery
-Relevant people
• Vegetation responsible
• Forest workers
• Landowners
• Operators
Is information updated? Have I reported necessary information to the right people?
-Correctness of entries
• Assess asset status information(4.1.1)
• Assess vegetation status information (4.1.2)
-Relevant people
• Vegetation responsible
• Technicians
• Forest workers
• Landowners
• Operators


4.3 Report status to the authoroties
4.3.1 Report recent outages
4.3.2 Report error analysis for previous year
Have I reported all required information?
-Status of ILE
-Status of KILE
• Cause category
• Operational stresses
• Construction
• Human
• Surroundings/ environment
• Assets
• Previous error
• Unknown
• Number of operational disruptions

5

CONCEPT

Concept

The holistic concept should solve the following challenges:

1. Currently, information and data is often spread among different systems, and the ability to compare relevant data from different sources is often lacking.
2. Communication between maintenance, operations, and fieldworkers (including lineman, drone pilots etc) is of varying quality, and none of the interviewed grid companies have satisfactory procedures or tools for sharing information or communication across departments.
3. Grid companies rely heavily on the individual experiences and empiric knowledge of individual employees, and this information is not made available, or entered into any systems.

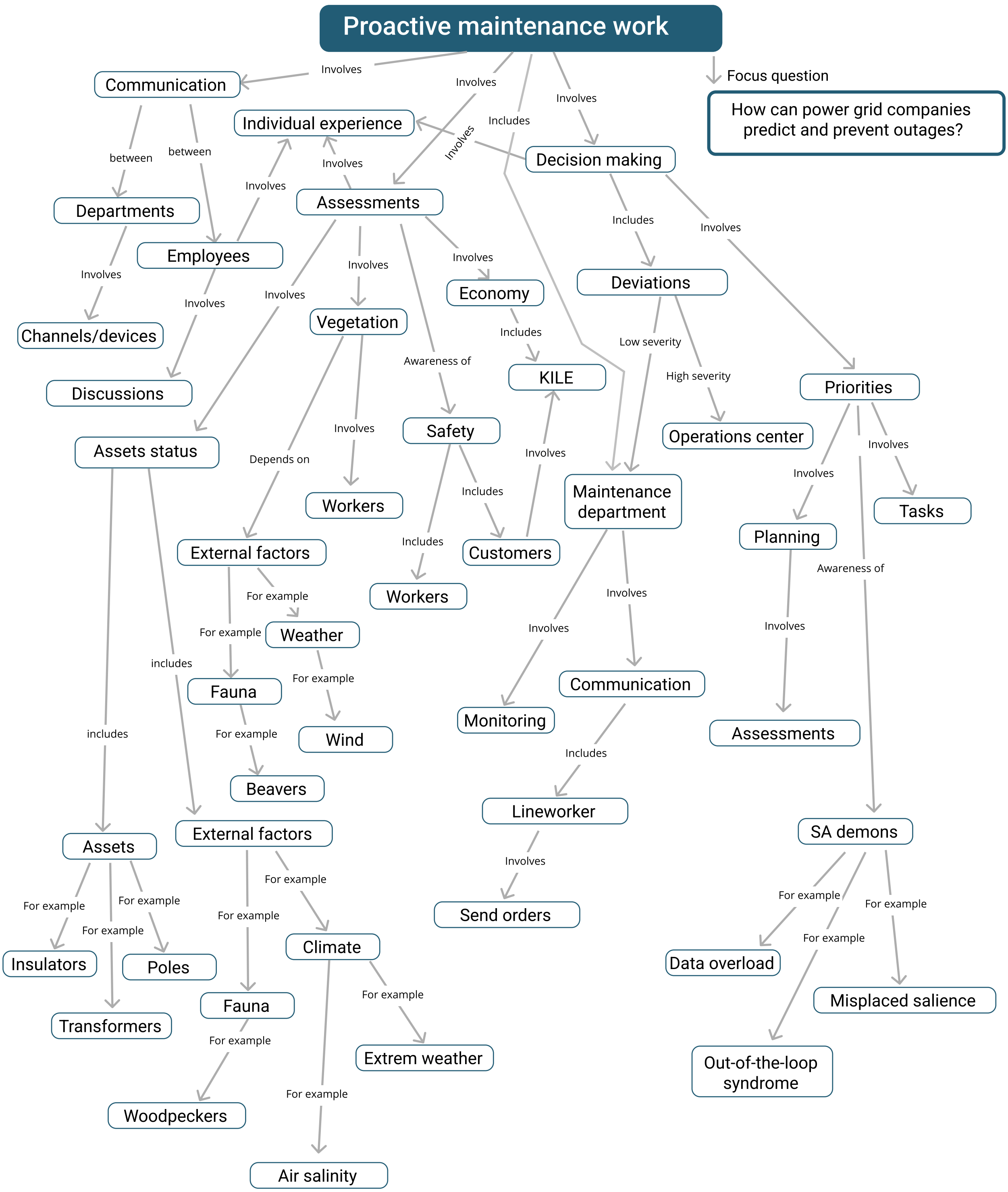
The MoSCoW method was used to clarify the requirements

MoSCoW

Must	Should	Could
Gather existing relevant data in a unified system	Allow sending inspection tasks to lineworker	Handle communication to customers
See relevant and context base information tailored to each role	Receive reports from field	Provide information about planned maintenance
Display vegetation/surroundings and risks	Show fauna, climate/weather and other relevant information for component life span	Generate reports to authorities
Display state of components/ equipment		
Display inspection data	Suitable screens and equipment in maintenance center ti improve overview	Show information/tips from customers
Visualize issues with severity		
Display warning on the most critical issues	Show experience based knowledge and historic data	
Enable communication between departments and roles		

Figure 5.1: MoSCoW

5.1 Concept map



5.2 Holistic concept

To solve the listed challenges, a holistic concept was proposed. Through interviews it became clear that there is a demand for a new unified system that can integrate all information and data relevant for the work of the maintenance departments. To collect and display the relevant information in context is a requirement to support level 2 SA. Such a system should in addition to integrating currently available data, also be adaptable to new technology and sources of information.

For the system to reach its full potential, it should be integrated into other grid company departments as well as external contractors. Lineworkers, inspectors, maintenance crews, and operators are examples of roles that should adopt the new system. This would allow for easier sharing of information between roles, and making relevant data available for other departments.

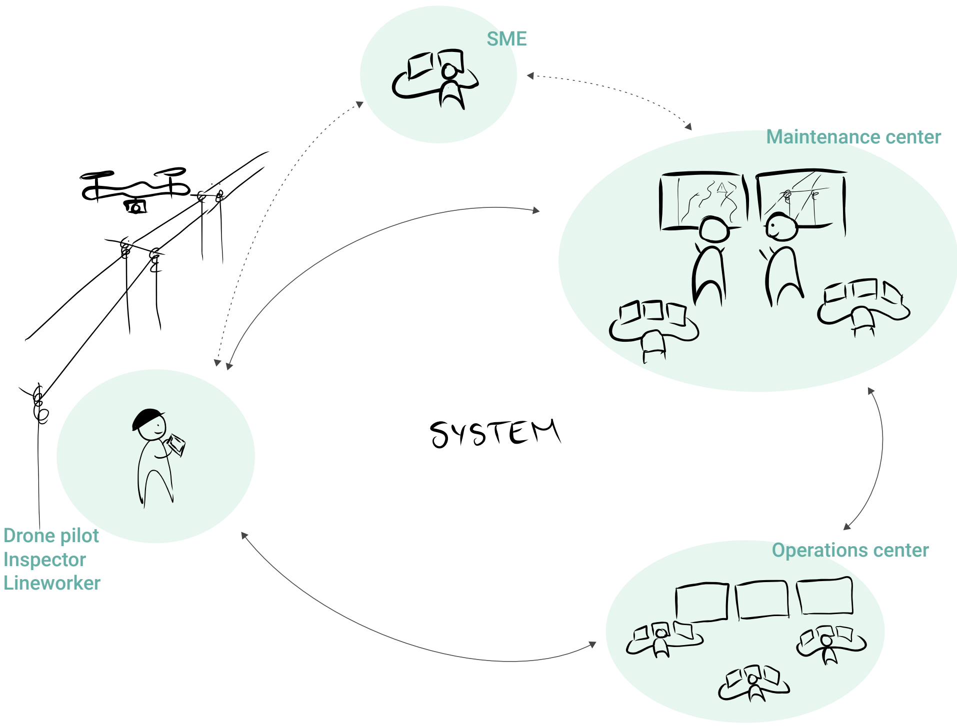


Figure 5.2: Holistic system

A Maintenance Center is the new proposed core of the system: By improving the situation awareness of the employees at the maintenance center it is possible to improve the ability to predict and prevent outages. Shifting maintenance employees from regular office stations to a dedicated maintenance center introduces new opportunities in presenting information in better ways to help improve SA.

Large screens with a holistic overview of the grid, with the ability to navigate to specific areas for closer inspection in either 2D or 3D, will allow maintenance workers to get a better feel for the state of the grid. By sharing a single location, employees can also be encouraged to discuss issues, and share in the decision making. This reduces the risk of individual misjudgements, as individual experiences can be better shared between employees through dialogue.

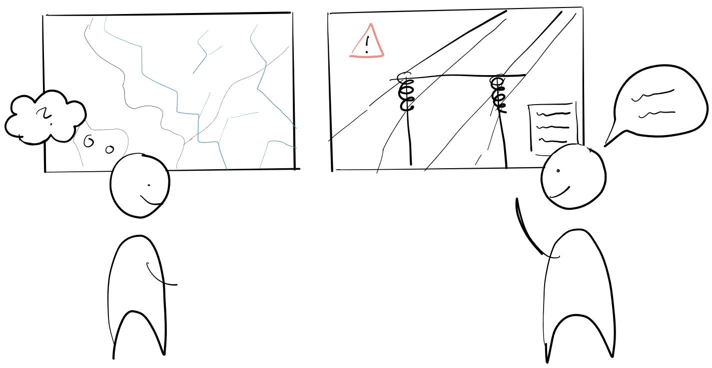


Figure 5.3: Maintenance Center

All maintenance employees should have their workstations at the maintenance center, and each worker should have a view of the system tailored to suit the information requirements of their assigned role.
The operation center should receive a map view of known deviations of high severity inside areas that suffer outages. The operation center should also have lines of communication to maintenance when attempting to recover from outages. This communication can either be a direct line, or a shared information system, so that the information is readily available to maintenance workers when they need to make decisions.

Drone pilots should have a version of the system adapted to tablet format and their information needs. They should be able to register relevant observations, so that this information is passed to the maintenance center (or to the operations center if required by the severity level). Ideally, the maintenance center and the operations center should be able to communicate directly to the drone pilots, and get live-view from the field, so that the need to send out field workers repeatedly is reduced. However, such a feature is dependent on sufficient network coverage, which is currently
lacking for large regions of the grid.

Line workers and other field workers should also have a role-specific version of the system, so the information from all parts of the grid can be kept up to date at all times.

For small grid companies with a limited number of employees and a lot of overlap between operations and maintenance, an obvious solution is to combine the maintenance and operation center in a single unit. This will create new challenges in terms of complexity, but will also make it easier to coordinate and share experiences between roles.

6

PROTOTYPE 0

Prototype 0

In prototype 0, some basic ideas behind how the system should be presented in a maintenance center were outlined. As all grid companies are different, with correspondingly varying needs and different ways of working, it is crucial that the solution can be adapted to each individual grid company according to how they organize their work.

Before further sketching and prototyping was done, it was very useful at this point to sketch a couple of personas and associated scenarios. The personas were carried out in workshop 1. The following associated scenarios became the starting point for the prototyping, as the concept is so comprehensive that it was not possible to solve all challenges and events.

6.1 Personas

Hilde

Age: 50

Title: Maintenance Manager

Education: Electrical engineer / technician / lineworker

Hilde works as a maintenance manager in a Norwegian grid company. She is interested in outdoorsmanship and fishing, and has a middling interest in technology. She is assertive and up to date in her field, and is interested in keeping up with recent events.. She is skilled in her field.

Needs & expectations:

- Error reporting independent of individual experiences. (Uniform error reporting?)
- Expects more automation in current tasks.
- Focus on having reported deviations from visual inspections registered and assessed.
- User friendly systemene

Pain points

- Dealing with different systems
- Different terminology across systems.

Goals:

- More precise and effective inspections.
- Enrich the system with her knowledge.
- Improve overview of grid with more detailed information on components.
- Overview on theoretical state value (Health index)
- Costs of replacing/repairing component
- Reduce cost (time/resources) of inspections
- Accurate identification of components.

Mathias

Age: 27

Title: Maintenance Worker.

Education: Electrician. Electrical Engineer. Trade school

Mathias works with maintenance in a Norwegian grid company. He likes to hunt and fish, and is an avid gamer. He is prideful and a career chaser, and a great detective in his job as a maintenance worker.

Needs & expectations:

- Priorities and efficiency
- Maximum resources
- High quality up-to-date documentation.
- Dialog and parity with other parts.
- Mentorship with more experienced employee.

Goals:

- Reduce KILE-kostnader
- Increase lifetime of existing equipment
- Better resource utilization
- Safety for workers

Pain points:

- Differing interpretations
- Maximize pay, minimize work hours.
- Access to tools

6.2 Scenarios

1. Hilde is reviewing next year's maintenance plan. She wants to find out which areas generate the most KILE, and which areas have historically yielded the highest KILE costs.

2. Mathias receives a new set of photos with findings from drone inspection. He chooses to first examine the most critical findings, in addition to comments from the drone pilot. During this inspection, the drone pilot had been told to examine a specific mast / line that was the site of the cause of an outage three months ago. Mathias turns to Hilde to discuss this specific case.

6.3 Rapid prototyping

The prototyping started with an overall wireframe, outlining the most important features.
The prototype is set up as a two-screen solution, and requires a 3840x1080 screen, or dividing the browser in two ordinary screens.

The first screen shows a map view of the selected area, and the second screen shows a close-up, 2- or 3d-view or video of a selected area. Selected location is marked with a pin on the map. Furthermore, map layer functionality is added, and the possibility to evaluate a picture from inspection compared with a previous picture from the same place.

There are two categories of map layers. The first category consists of the physical parts of the grid, like distribution grid and transformer stations. These layers should adapt to the zoom level, as showing too detailed information, like all power poles, will quickly clutter the view when selected at a high zoom level. The second category is information layers. These are meant to be for instance wind, KILE, historical incidents, vegetation risk etc. The interaction implemented matches scenario 2, where Mathias receives a new set of photos from drone inspection. Matthias also receives comments from the drone pilot.

The selected area has no connection with the grid companies involved. Regional- and distribution grid and transformer substations are taken from NVEs power grid map (NVE, n.d.) Rest of the information in the prototype is fictitious, but some information is based on real events from fieldwork. However, this information is placed in other geographical locations than where they occured. A big thank you to Magne Kaspersen from Skogdrone for providing photos and video for the prototype.

6.4 User test and feedback

Prototype 0 was tested by an electrical engineer at Verico, who works as a SME. The main goal of this user test was to get some feedback on setup and UI, and the idea of a map layer based and role-specific system.

The tasks were solved without problems, and the feedback was that the prototype was intuitive and provided a good overview. What was not intuitive for the tester was why the layers were non selectable. The tester assumed that one layer must be deselected, before a new one could be selected.

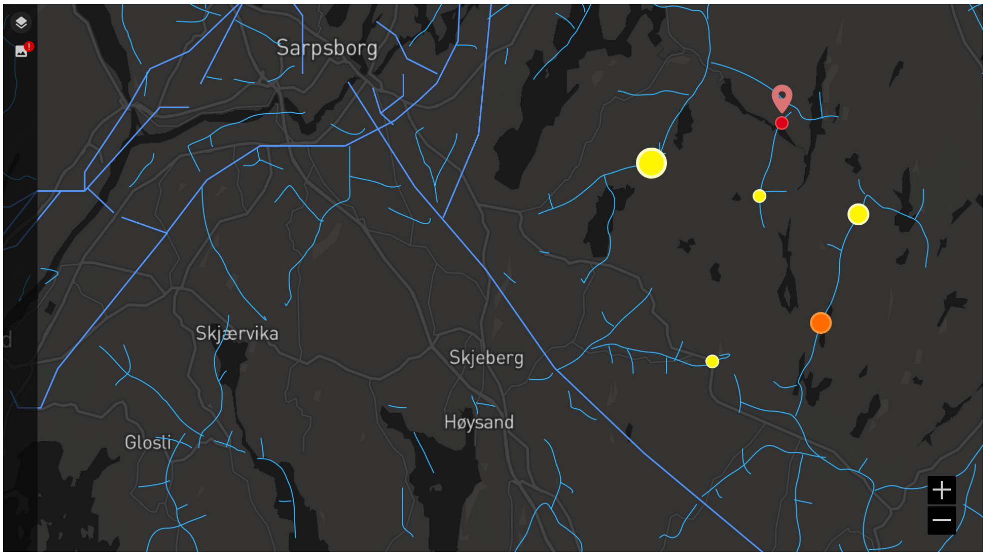


Figure 6.1: Prototype 0, screen 1

Figure 6.2: Prototype 0, screen 2

7

PROTOTYPE 1

Prototype 1

In prototype 1, some more interaction was added. In this prototype, functionality matching both scenarios was implemented.

7.1 Prototyping

Both improvements and new functionality were added. Some improvements were based on feedback from previous user tests, and some were based on my own thoughts and ideas through the process.

KILE was added as information layers. The idea is to visualize KILE-costs, as KILE was found to be one of the most important information requirements in the GDTA and insight process. KILE is an important metric for all involved grid companies, and is not visualized in their existing systems. Grid companies rely on individual user experiences to know historical KILE costs of different areas.
To visualize this information and present it in context with other relevant information, will improve both level 1 and level 2 SA, and leave the grid companies less dependent on their employees' individual experience.

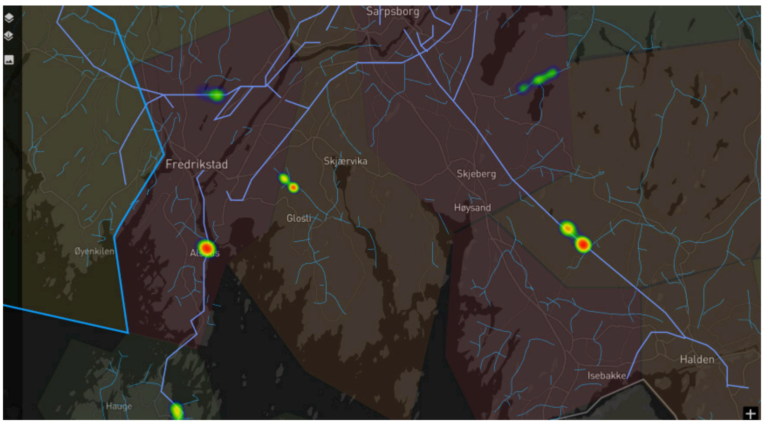


Figure 7.1: Prototype 1, KILE

Several considerations were done:

Screen 2: overview/statistics and closeup
Screen 2 shows a specific location in the grid, to help the maintenance worker assess status. But what if no location is chosen?
Earlier in the sketching process, an overview with statistics for an area was considered as required information. However, there was no space for such information in the existing framework without risking data overload and misplaced salience. The solution should be to show either close up images/video OR overview statistics, since these two types of information are not relevant at the same time. In this way, the user gets rid of unnecessary information for the current task. If the user wants to evaluate the state of a power pole, the user does not need information/statistics for a larger area. This follows design principle 1, as explained in chapter 2.

Map layers
The idea to visualize most information in map layers, can undermine SA. During the prototyping, it became clear that not all information is relevant as map layers. For instance, the beaver population is only relevant if it poses a risk of tree over lines. To show all information as map layers, can lead to both data overload and misplaced salience. It should only be possible to see map layers in relation to each other, if the context gives valuable information. For instance, wind will not be relevant when assessing asset status, but of great importance when assessing vegetation risk.

Notification/alarms
Use of alarming notifications must be done with caution. The idea is to match the color of the notification with the severity of found deviations. The tendency to add alarms has grown out of control in many domains. Many systems are plagued by high false alarm rates, leading to the cry wolf syndrome. This means the operator will have a low confidence in the alarm, and may ignore those alarms they believe to have low reliability. (Endsley & Jones, 2012)

7.2 User tests

Since the user testing had to be done remotely, the prototype was customized for a one-screen view. This limited the quality of the display, but the user test still provided valuable feedback.

The first tester was the same as in prototype 0, a SME from Verico.
The other tester was an operations and maintenance manager in a small Norwegian grid company.
Both testers were positive about the visualization of KILE-costs in the map. They said this provided useful information. However, the manager commented that the colored areas that were supposed to represent KILE-areas, were not accurate. KILE should be divided into smaller areas, and match the divisions in the grid.

Both testers were confused by the transformation stations that were added as a layer. These were shown as small, light red squares, inspired by the map from NVE (NVE, n.d.)
Both immediately interpreted these as incidents. When they were asked to remove the transformation stations from the map, they seemed surprised that the squares were supposed to be transformation stations.

They were positive about the user interface, and pointed out that this would be an improvement from existing systems.
The manager suggested improvements for the KILE feature, for instance showing historical data based on KILE-costs. This data will highlight areas that have generated the most KILE during the selected time frame. He added that the historical incident feature still is relevant in addition to historical KILE. Even if a customer does not generate a high KILE, they have the same right to a reliable supply. It is therefore important to see repeat issues independently of their KILE generation.

8

PROTOTYPE 2

Prototype 2

In the next iteration, some minor improvements were done, in addition to some more elements.

8.1 Improvements

Videos were converted to gifs, as Figma does not support videos. The gif is meant to simulate video from drone inspection.

To separate the two groups of map layers, a new icon was made. A traditional map layer-icon combined with an information-”i” is used as a button for choosing information layers.

The transformer stations are marked with new icons, inspired by the form of a transformer, and colored blue, to not confuse the user as the previous user tests revealed.

The historical data is divided into historical incidents and historical KILE, as suggested by the manager in the previous user test. More information was added to this feature when clicking on the heat map.

The ability to choose a time frame for statistics and historical data was added.

Figure 8.1: Information layer icon

8.2 User test and feedback

Prototype 2 was tested with the same testers as prototype 1. The improvements received positive feedback, and some more improvements and suggestions were mentioned. The ability to choose “last year”, “last 3 years” etc did not match the maintenance manager’s need, and he would rather use the calendar to choose the desired period.

Both testers intuitively understood the information-layer icon. The maintenance manager thought the historical KILE feature was valuable. He also suggested adding the ability to zoom further and see what customers that were affected by the outage, and how they could prioritize the most “important” customers.

The SME added that a system with an intuitive user interface like this would be appreciated by maintenance workers in a power grid company, as the existing systems are often difficult to use.

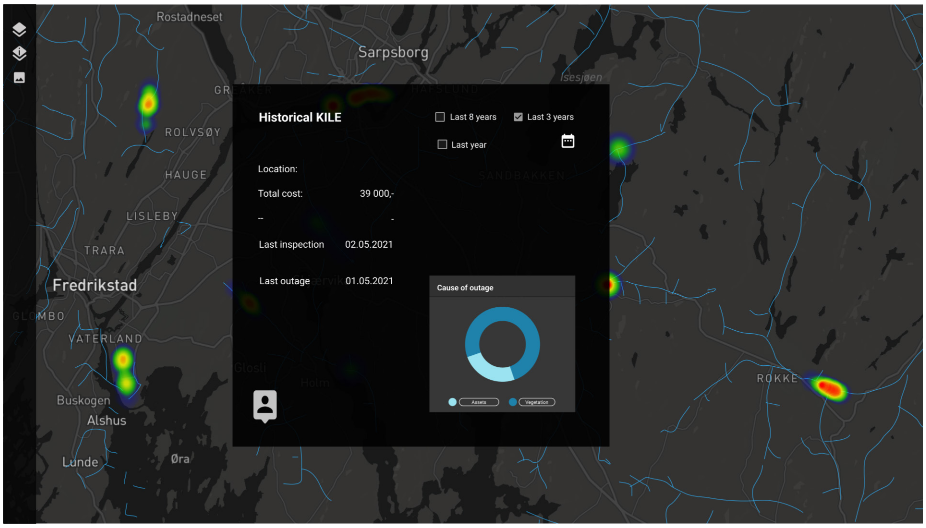


Figure 8.2: Prototype 2, screen 1

Thoughts
When the prototype follows a specific scenario, the available information and possible interractions are limited to the pre-defined solution path. This limits the ability to test the challenges caused by the complexity in a real solution. Despite this, the proposed framework can be used as a starting point, where the focus is to combine relevant information tailored to the needs of the user. For instance, by looking at a visual representation of KILE along with the most common factor of outages in an area with high historic KILE costs the users SA can be improved.

Link to prototype:
https://www.figma.com/proto/XRM5KnuTNtqOMwqQqahuUE/Prototype2?page-id=0%3A1&node-id=23%3A5620&viewport=241%2C48%2C0.22&scaling=min-zoom&starting-point-node-id=2%3A5245&show-proto-sidebar=1

Figure 8.3: Prototype 2, screen 2

9

FUTURE SOLUTION

Future solution

In the following sections, existing challenges are discussed, followed by recommendations for future solutions.

9.1 Challenges

There are several challenges when planning a new, holistic system. One challenge is the inconsistency of both terminology and symbols across the grid companies today. This should be standardized, which will be a comprehensive process that will require acceptance and cooperation from all grid companies.

Further, the SA demon data overload will become more and more relevant as the amount of data increases drastically. Automation will be necessary to reduce the workload, but must be done with caution to avoid the out-of-the-loop syndrome.

A reliable grid is becoming increasingly important, and the power grid is vulnerable to outages. Therefore, it is important to start the work of developing a more comprehensive solution, as the challenges that the grid companies face today will be even greater with increasing amounts of data and new technologies. A major challenge of such a comprehensive system will be the danger of cyber attacks, as parts of the system will be dependent on network connection.

9.2 Recommendations

The user interface of this system will quickly become very complex, containing vast amounts of data, and steps should be taken early to prevent complexity creep. The following suggestions can help dealing with such complexity:

1. Role-specific versions of the system, with information matching the role's goal. For instance, asset view and vegetation view should be separated in most grid companies. This is in accordance with design principle 1. (Endsley & Jones, 2012)
2. It should only be possible to see data and information in relation to each other, if the context gives valuable information. This is in accordance with design principle 2. (Endsley & Jones, 2012)

With the ongoing digitization and the endless possibilities provided by new technology, it will be more important than ever to utilize user centered design processes to ensure that users have adequate SA in order to minimize so called "human errors".

The GDTA will be an important tool in the process of creating a more holistic system, in order to ensure that only relevant data and information is presented, and that relevant contexts are made clear. To ensure that the system is well suited for each role, it would be beneficial to perform a GTDA adapted for each role.

It should also be noted that such a system will never be finished, but needs to be dynamic and adapt as new demands, information or technology becomes available.

The grid companies are often influenced by technology driven processes, and it will be important to focus on user centered design to face both today's challenges, as well as those that come with the digital revolution. It will be important to increase the use of designers in these processes than we are seeing today, in order to ensure systems that are manageable by the users.

10

THOUGHTS & EXPERIENCES

Thoughts and experiences

Focusing on technology and the opportunities it provides, the idea for this master thesis was to develop an innovative concept that utilizes AI and other technologies under development by eSmart Systems. During the course of the project, it became clear that one of the main challenges grid companies face today is how to handle and process the data that they already have available. To not add even more data, and further strain the users SA, the primary focus of the project was shifted to focus on the needs of the users, and how they can achieve high level SA. The user centered design process led to a different result than originally expected, as basic challenges with the current data overload and communication issues were considered as a more beneficial way of increasing the users SA.

It would be beneficial to focus on solving the basic challenges the grid companies face with their current systems, and begin the process of creating an all-encompassing system with a focus on the users goals and SA. The concept presented in this thesis is envisioned as a starting point for such a system that should act as a modular platform for further implementation of new technological solutions. By including SA-oriented design processes in the development of such a system, the risk of design-induced errors (so-called human errors) can be decreased.

10.1 The GV5D Process

The opportunity to participate in user forums and workshops organized by eSmart Systems has been very important for my insight into the power grid domain. Being a part of the early phases of the project has been a very interesting challenge, and a great learning experience.

eSmart Systems has historically been dominated by technology oriented processes, something that is still prevalent today. My experience from this project is that the focus is still on implementing new technologies, and how these technologies can provide new opportunities for the customers. This is both an advantage and a potential weakness for eSmart. They have an advantage in being on the leading edge of research and development, and are very competitive in the market. At the same time technology-centered design is associated with several issues. Technology-centered design has been the traditional method for developing systems. Engineers develop sensors and systems needed to perform a given task, and this is then often presented in a single view for each system. The challenge is that as more technological solutions are added, the number of sensors and systems keep increasing, and presenting the data becomes more and more difficult. The user is then faced with the increasingly difficult challenge of being aware of all the different systems and presented data. (Endsley & Jones) This has been a challenge for product development at eSmart, something they confirm.

Simultaneously, eSmart has involved the user group early in the GV5D process, and has maintained close communication and involvement through the workshops and user forums. In this way eSmart has gathered insight into both the challenges that grid companies face, and their thoughts on the suggested sensor solutions. This is quite close to the co-design process, and shows that technical workshops and user forums used in this manner can provide valuable insight into which technological solutions to pursue. Maintaining this interaction with the users will continue to prove important as the project moves towards the prototyping phase. This will allow them to develop a system that ensures good SA, while avoiding the data overload and other SA demons, while also creating an intuitive user interface.

Although the origin of the project was based on hypotheses regarding specific technologies and their possible uses, instead of mapping the needs of the user, they still include the users through the entire process, providing valuable insight. it now appears as the process with its current design tools is providing valuable insight to the company.

The addition of in-house designers has undoubtedly been a great benefit for eSmart, and I believe that by further strengthening the design department by adding more resources, eSmart can implement more user centered design processes. This is something they do not have the resources to effectively manage today, as the current designers are spread too thin with their current tasks and responsibilities.

10.2 Design Process

One challenging aspect of the design process was the restrictions imposed by the response to the COVID-19 pandemic. For parts of the project it was not possible to visit the grid company sites, and all meetings and user interaction had to be done online. For a complex domain like the power grid, observing the user group in their daily tasks in the intended environment would have been valuable. It was also difficult to test multi screen solutions when the users often used home office with limited display capabilities. Despite this, it has been a valuable experience to use digital tools for so many aspects of communication. This has also showcased the importance of tools such as Figma and teams, that allow for communication and user testing online.

It was also quite challenging to work on the project and follow the design process alone. Attending meetings and workshops, and having weekly meetings with my contact at eSmart and my supervisor was also a great help. However, the pandemic and the challenges it brought meant that the process was affected by the reduced contact with users and other involved parties. For a project that requires deep insight into a complex domain, where a lot of time was spent trying to understand the domain, sort insights, and review possible solutions, working in a team, preferably cross discipline, would have been beneficial.

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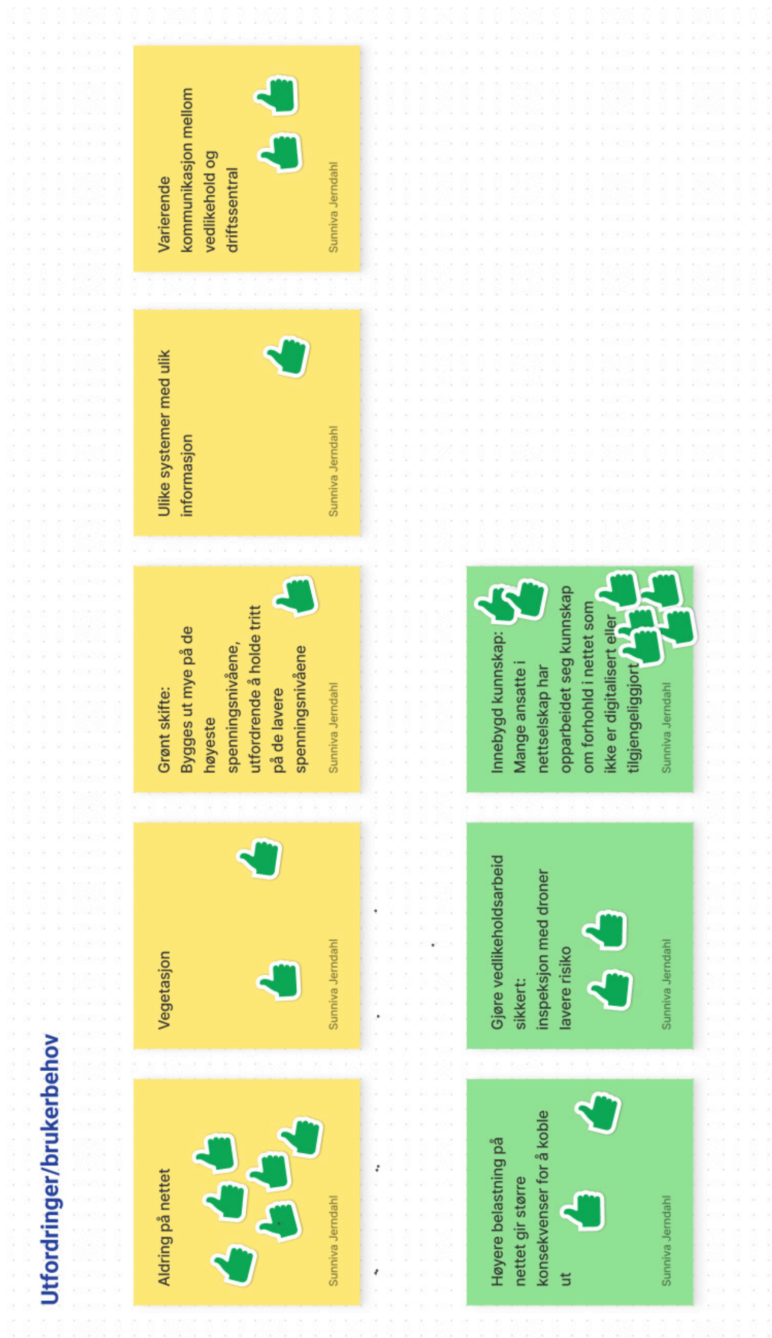
APPENDIX

Appendix A



WS0


1
Oppdatert informasjon om linjene/dokumentasjon
Godt etablert dialog med driftssentralen
Programmer som gjør oversikt over linja/ inspeksjon enklere og mer automatisert.
Dokumentert oversikt over historisk data. Er det feil som stadig gjentar seg på samme sted?
2
God visuelle dokumentasjon på tilstand til nett
All krevd informasjon for utførelse av vedlikehold samlet et sted
Gode verktøy for prioritering av vedlikeholdsoppdrag
God kontroll på trasen (vegitasjon, topologi++)

3

Rikt asset bibliotek med mulighet til å se nettet i ulike sammensetninger:

- Region
- Linje
- Mast
- Komponent

Muliget til å se status på utstyret i de ulike nivåene.

Visning av asset/master i kart med ulike visningslag:

- topologi
- vegitasjonsrisiko
- tidligere utfall

Mulighet til å kommunisere mellom ulike grupper med brukere i samme løsning slik at vedlikeholdslederen kan kommunisere med for eksempel en inspektør eller driftssentralen i kontekst av en region/linje/mast/komponent

Mulighet til å lage oppfølging/oppgave/task i systemet for andre systembrukere eller deg selv.

Kan også brukes til å berike informasjonen til en komponent.

Mulighet til å inspisere nettet ditt litt på samme måte som man bruker Google Street view

Mulighet til å jobbe prevantivt med anbefallinger fra systemet om hvilke handlinger du som bruker bør foreta deg i systemet med tanke på planlegging/vedlikehold/osv.

4

Förbättrad kunskapsdelning mellan inspektörer med olika kompetenser och erfarenhet

Standardiserad inspektion och sammanställning av resultat för att öka kvalitet och tillgänglighet i rapport över nätets tillstånd

Förbättad informationsdelning mellan avdelningar, tex driftscentral och vedlikehold genom tex standardiserade rapporter

Analysverktyg för att kunna dra snabbare och bättre slutsatser av genomförda inspektioner

Analys av hur olika faktorer påverkar risken för problem, tex hur ålder på utstyr påverkar risken för olika typer av fel

Analysverktyg för att kunna använda information från både inspektion (tilstånd) och driftcentral (konsekvens av strömavbrott vid olika tidpunkter) för att bättre kunna planera vedlikehold

5

Tilgjengeliggjøre innebygd kunnskap i en kartvisning

Samle alle relevante datatyper/informasjon i et system

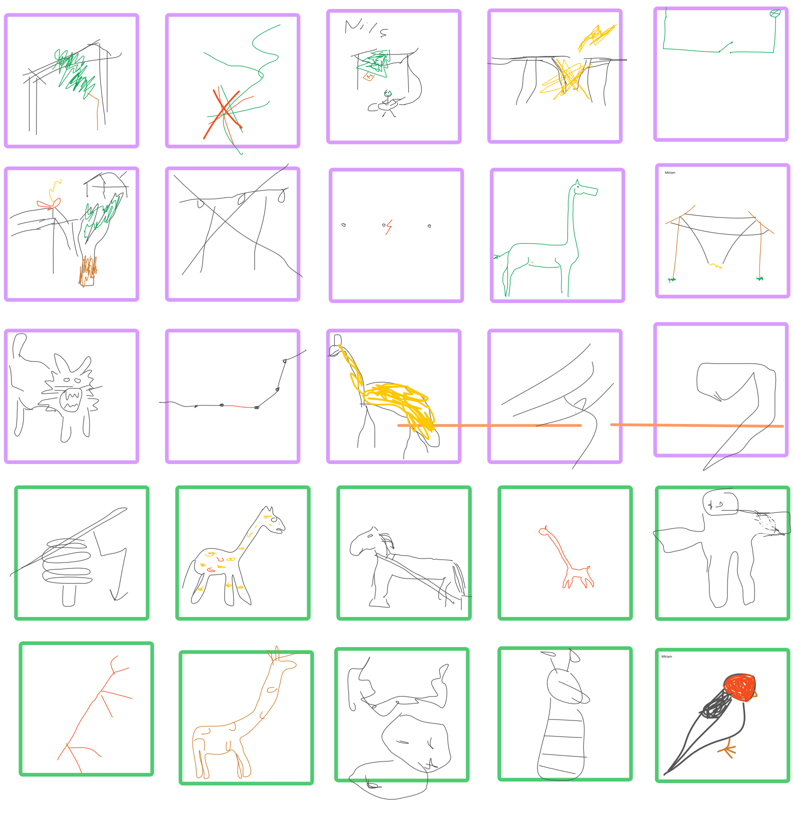
Visuell visning av nettet

Kommunikasjon med driftssentral om tillatelser til utkobling for vedlikehold

Et samlet system som kan tilpasses rollen (hvilke datatyper er relevant for Geir/ andre roller)

Sunniva Jerndahl

Appendix B




Aldring på nettet
Sunniva Jerndahl
Vegetasjon
Sunniva Jerndahl
Ulike systemer med ulik informasjon
Sunniva Jerndahl
Høyere belastning på nettet gir større konsekvenser for å koble ut
Sunniva Jerndahl
Gjøre vedlikeholdsarbeid sikkert:
inspeksjon med droner lavere risiko
Sunniva Jerndahl
Innebygd kunnskap:
Mange ansatte i nettselskap har opparbeidet seg kunnskap om forhold i nettet som ikke er digitalisert eller tilgjengeliggjort
Sunniva Jerndahl
Grønt skifte:
Bygges ut mye på de høyeste spenningsnivåene, utfordrende å holde tritt på de lavere spenningsnivåene
Sunniva Jerndahl
Varierende kommunikasjon mellom vedlikehold og driftssentral
Sunniva Jerndahl

2

Hvis man skal ha bruk for en 3D-modell, må bilder og data være hyppig oppdatert.
som kanskje betyr at man må ha en billigere alternativ løsning på befaring. automatisk selgående drone?

Automatisert detektering av avvik.

6

Restlevetid på komponentene.

Få inn muliheten for potensiell feil.

Kartlegging av vedlikehold. (prioritering)

Montører i felt kan rapportere digtalt.

Kommunisere mellom div programvare

3

Automtisk rapportproduksjon

Mobilløsning som publikum / montør kan sende inn direkte til nettselskap

Høydedata fra sensorinnsamling kan bruks til å registrere høyde-koordinat på komponenter i NIS

Automatisk definering av risiko for feil/trepåfall

Automatisk soneinndeling for å knytte avvik geografisk i samlinger

4

Helseindeks:
Få inn sannsynlighet for feil og konsekvens av havari

Bra metodikk smo ble vist i møtet i morges med risikobasert tilnærming

Videreutvikling av dashboardet i Grid Vision

Kanskje gjøre dashboardet rollebasert. Et for montør, et for vedlikeholdsleder, et for prosjektleder osv

Real-time sensordata inn i Grid Vision

Kobling mot innkjøp og logistikk

Viktig med godt samspill med NIS-system og økonomisystem.

Kobling mot 3D-gravedata slik at man får en fullstendig 3 D modell av hele nettet inkludert kabler.

5

Ha god oversikt over komponentenes helsetilstand og raten av degradering. Ut fra driftsrelatere data og miljø og andre faktorer.
For prioritering av vedlikeholdsarbeid er en god oversikt over konsekvenser, helsetilstand og kostnad interresant. (Hvilke komponenter må det følges med på)

Informasjon som kan tenkes brukt i forbindelse med en utregnet helsetilstand/ degraderingsrate Observasjoner om nåtilstand, produsent, lot, materiale, estimertlevetid (fra produsent eller reliability database), eventuelle belastninger dersom dette påvirker levetid. Lokasjonsdata dersom levetiden påvirkes av dette lufttemperatur, vind nørhet til kyst (salt)

Nyttige sammenhenger for å se de økonomiske konsekvensene er hvor stor potensiell KILE det er for de ulike områdene.

Se utviklingen av tilstand over tid

6

Verktøy som forutser potensielle feil før det går galt.

Enkel oversikt over historisk data. Hvilke feil skjer ofte på hvilke steder osv.

+1

Verktøy som hjelper til med å prioritere feil og utbedringer

God og oppdatert oversikt over hele linja

7

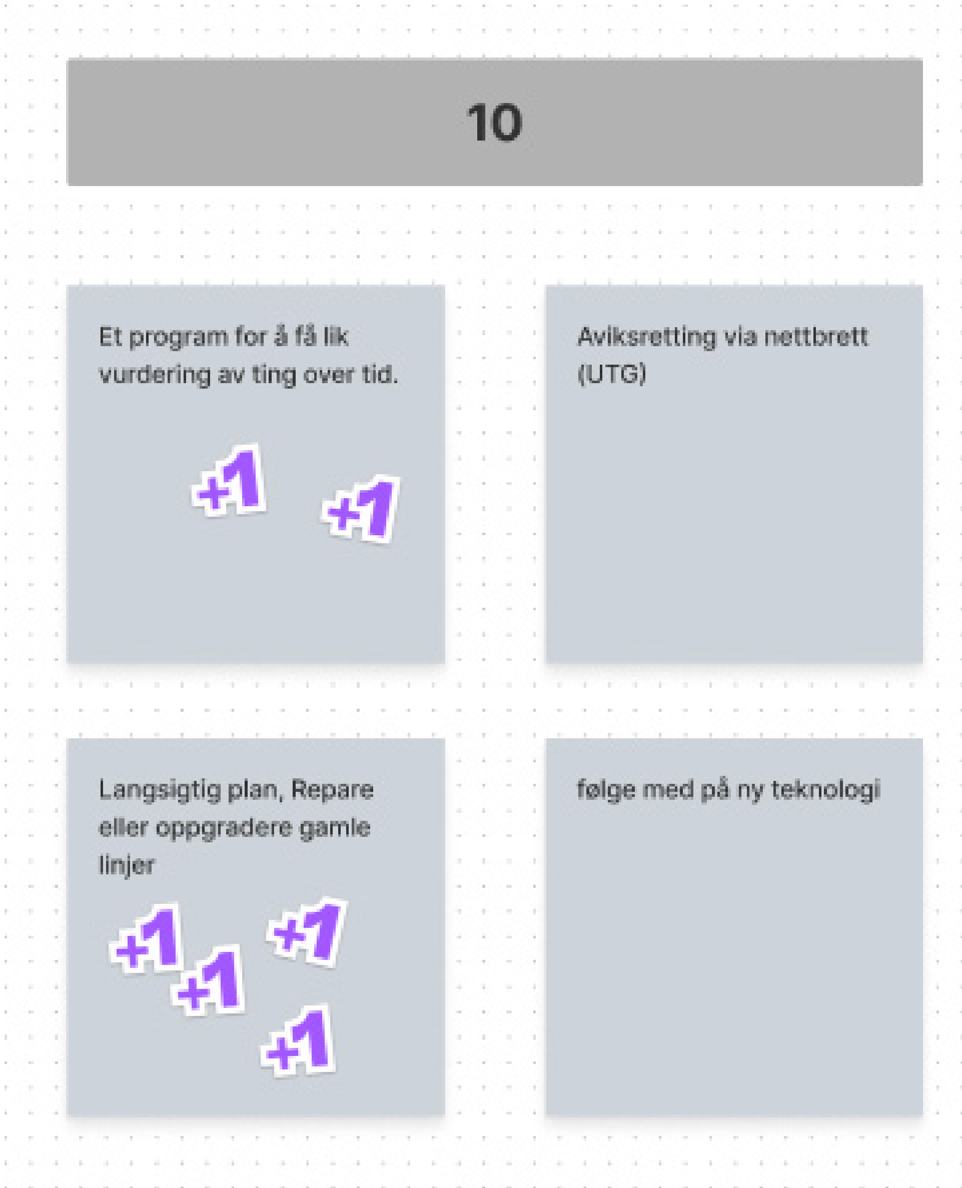
Verktyg som underlättar att identifiera på ett tidigare stadie vilka komponenter som kommer behöva bytas ut för att ha framförhållning i beställningar

Bättre dataunderlag och analysverktyg för att avgöra när en komponent behöver bytas ut. För att minska risken att komponenter byts ut för tidigt eller för sent och att bedömningen görs mer systematiskt och likartat oavsett vem som gör det

Möjlighet att få ökat stöd som nyanställd/oerfaren från mer erfarna kollegor


8
Informasjon om tidligere hendelser i gitt område/ på gitte master
Kolleger å diskutere avvik med for å vurdere risiko
+1
+1
Helhetlig oversiktsbilde på store skjermer. miniversjon driftssentral? vedlikeholdsversjon
Add text


9
Program som GV som gir oversikt over feil som må prioriterast
Oversikt over anlegget: Alder, oftere utfall, vegetasjon osv.
Deler som oftere må befares?
+1
+1
+1
+1
+1
+1
Forståelse av kva som kan stå og kva som må utbedrast
+1
Add text


10
Et program for å få lik vurdering av ting over tid.
+1
+1
Aviksretting via nettbrett (UTG)
Langsigtig plan, Repare eller oppgradere gamle linjer
+1
+1
+1
+1
følge med på ny teknologi

11

Samme mål i hele organisasjonen

+1 +1 +1 +1

Grønne skifte gjør at det må bygges om der lasten er høy og kanskje ikke der vår person ønsker.

+1 +1

Resurser til å utføre det han prioriterer høyt.

+1 +1

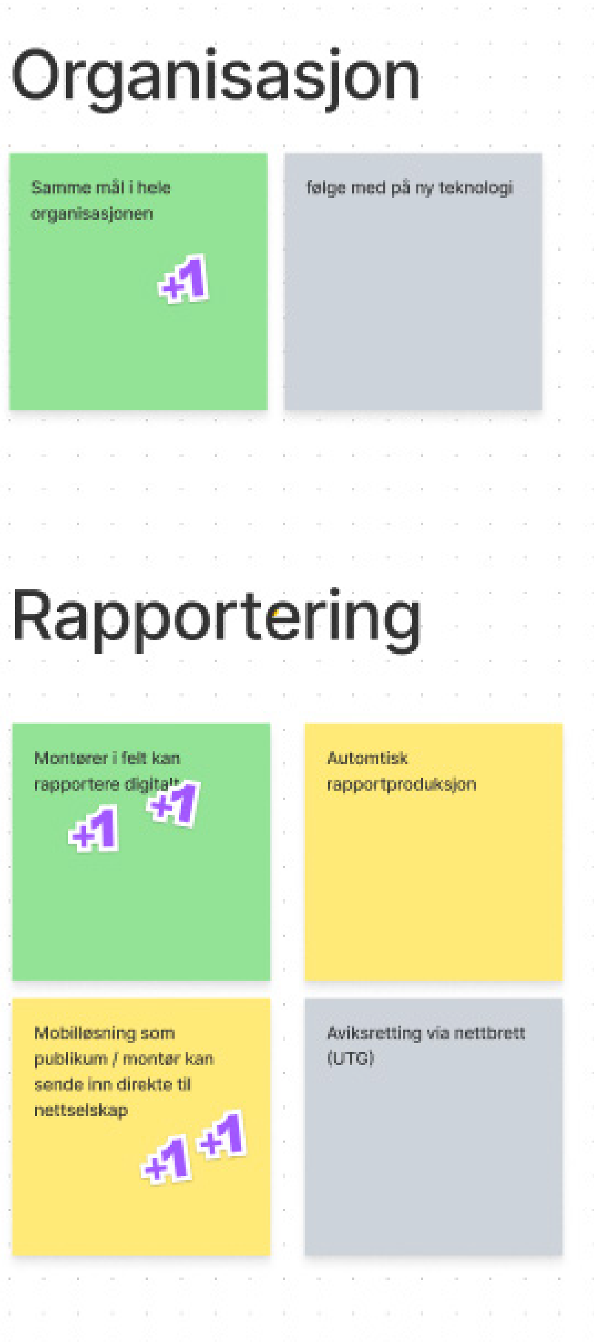
12

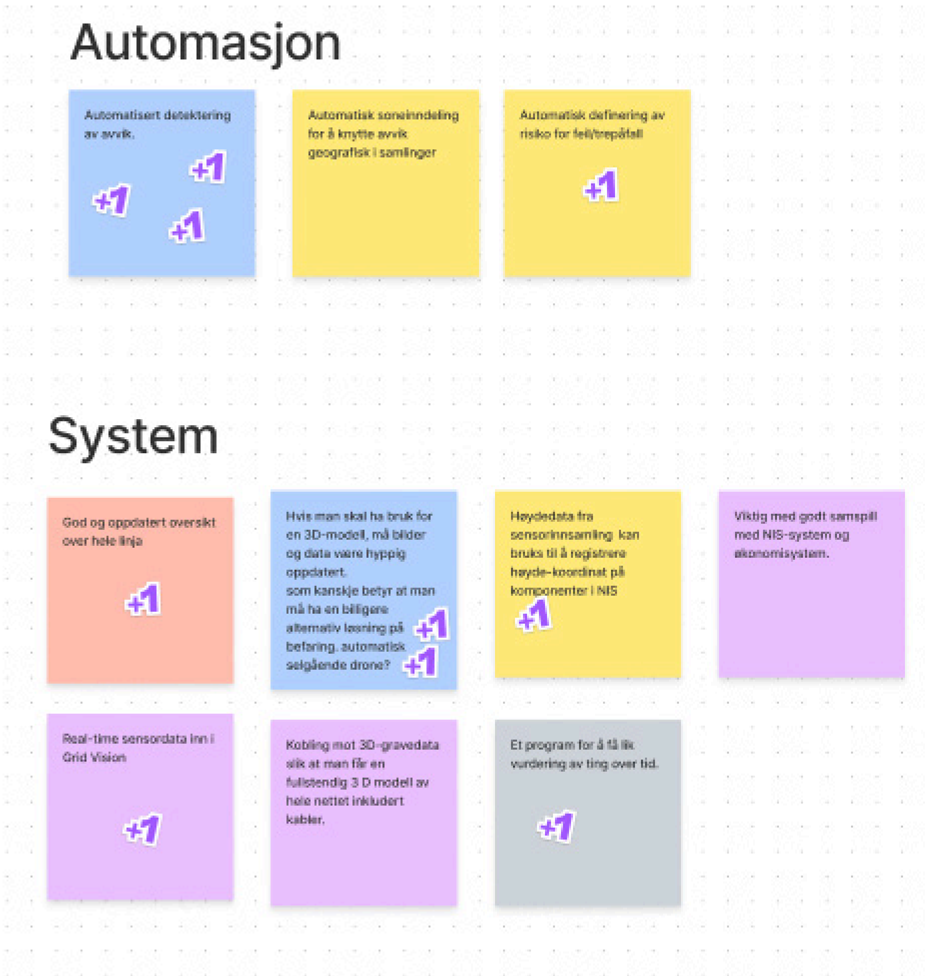
Bedre kontroll på holdbarhet på komponenter i ulike klima/ andre påkjenninger.

+1

Få et helhetlig bilde av en linjestrekning (kile, risko, feilsannsynlighet m.m). Utvikling over tid. Kunne sammenligne med andre strekninger.

+1


Organisasjon
Samme mål i hele organisasjonen
+1
følge med på ny teknologi
Rapportering
Montører i felt kan rapportere digita
+1
+1
Automtisk rapportproduksjon
Mobilløsning som publikum / montør kan sende inn direkte til nettselskap
+1
+1
Aviksretting via nettbrett (UTG)

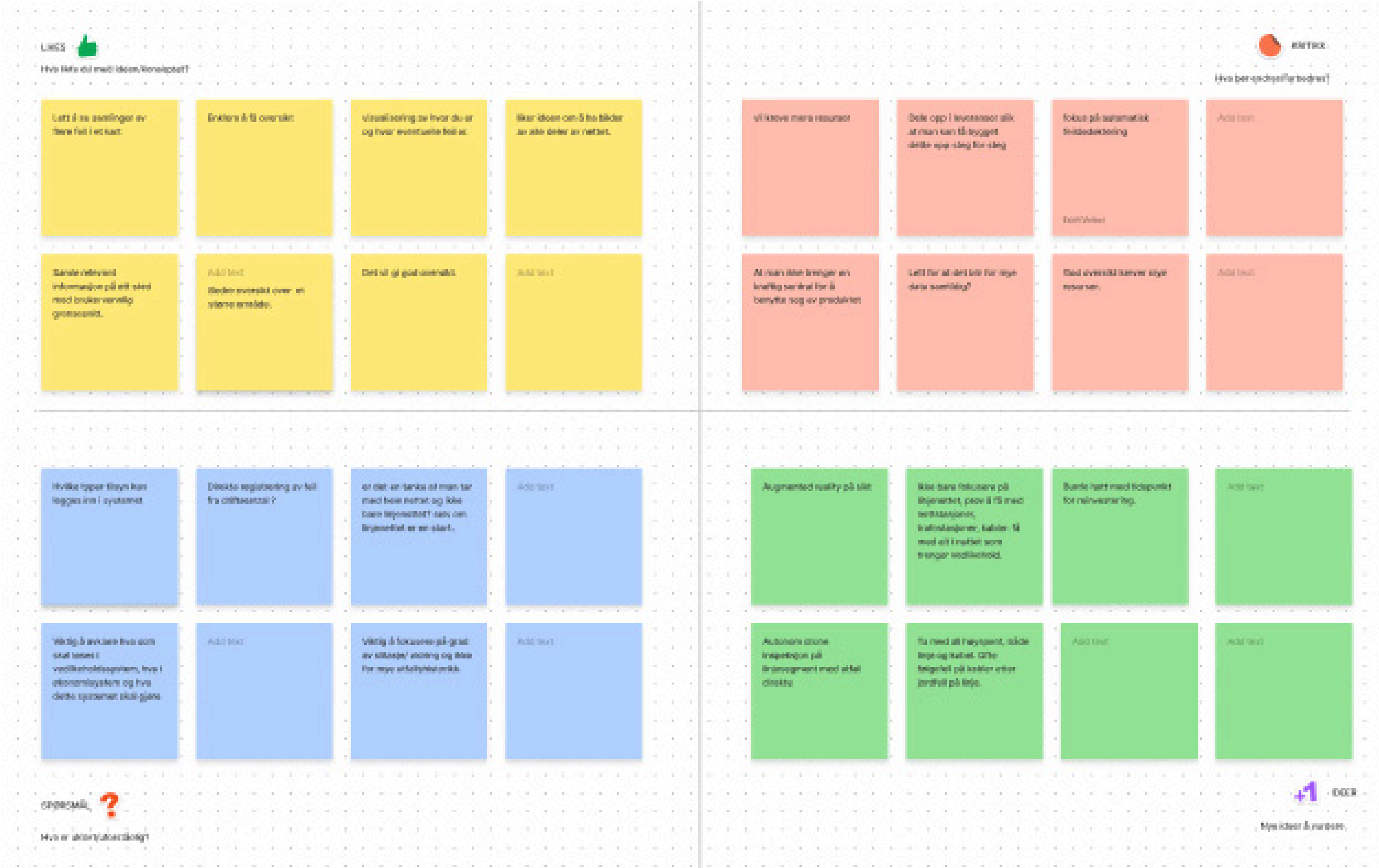

Automasjon
Automatisert detektering av avvik.
+1
+1
+1
Automatisk soneinndeling for å knytte avvik geografisk i samlinger
Automatisk definering av risiko for feil/trepåfall
+1
System
God og oppdatert oversikt over hele linja
+1
Hvis man skal ha bruk for en 3D-modell, må bilder og data være hyppig oppdatert.
som kanskje betyr at man må ha en billigere alternativ løsning på befaring. automatisk selgående drone?
+1
+1
Høydedata fra sensorinnsamling kan bruks til å registrere høyde-koordinat på komponenter i NIS
+1
Viktig med godt samspill med NIS-system og økonomisystem.
Real-time sensordata inn i Grid Vision
+1
Kobling mot 3D-gravedata slik at man får en fullstendig 3 D modell av hele nettet inkludert kabler.
Et program for å få lik vurdering av ting over tid.
+1

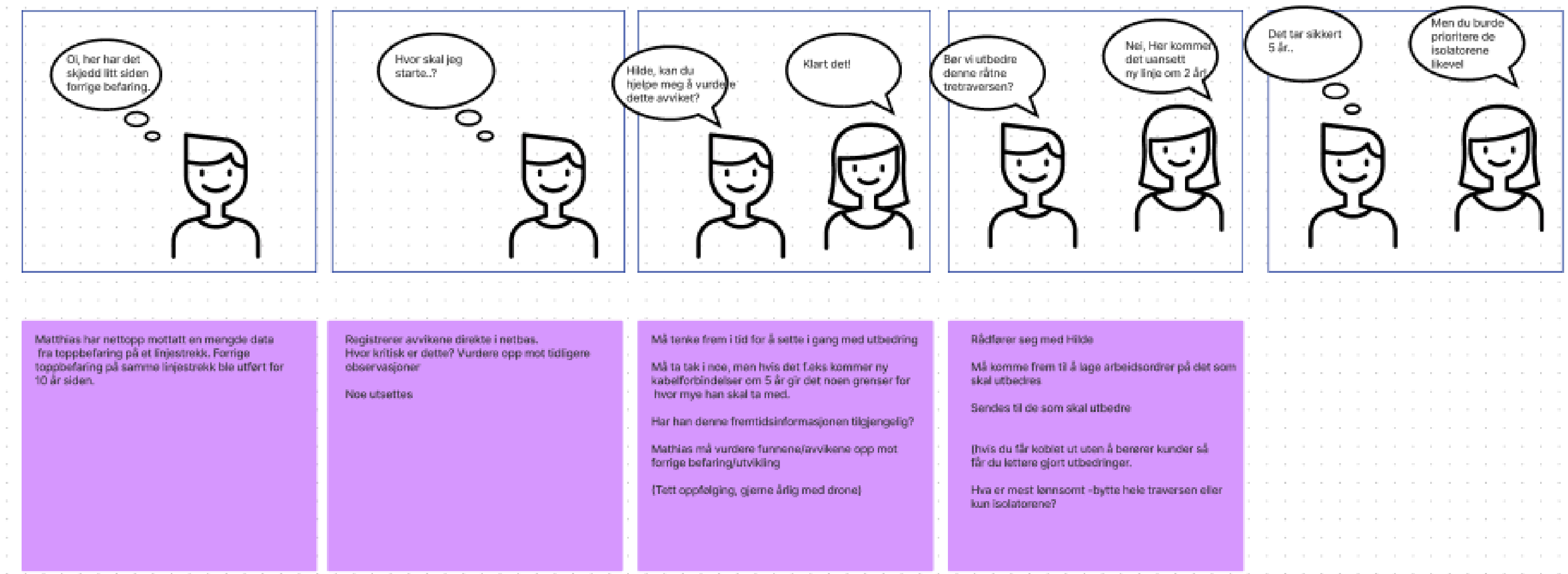

Prioriteringer
Verktøy som hjelper til med å prioritere feil og utbedringer
Resurser til å utføre det han prioriterer høyt.
Grønne skifte gjør at det må bygges om der lasten er høy og kanskje ikke der vår person ønsker.
Langsigtig plan, Repare eller oppgradere gamle linjer
Kartlegging av vedlikehold
Historikk
Informasjon om tidligere hendelser i gitt område/ på gitte master
Enkel oversikt over historisk data. Hvilke feil skjer ofte på hvilke steder osv.
Arbeidsstasjon
Helhetlig oversiktsbilde på store skjermer. miniversjon driftssentral? vedlikeholdsversjon

Samarbeid og kommunikasjon
Möjlighet att få ökat stöd som nyanställd/oerfaren från mer erfarna kollegor
+1
Kolleger å diskutere avvik med for å vurdere risiko
Kommunisere mellom div programvare
+1 +1
Videreutvikling av dashboardet i Grid Vision
+1
Kanskje gjøre dashboardet rollebasert. Et for montør, et for vedlikeholdsleder, et for prosjektleder osv
Kobling mot innkjøp og logistikk
Være med på vaktmøter.
Økonomiske konsekvenser
Få et helhetlig bilde av en linjestrekning (kile, risiko, feilsannsynlighet m.m). Utvikling over tid. Kunne sammenligne med andre strekninger.
+1 +1 +1 +1 +1
Nyttige sammenhenger for å se de økonomiske konsekvensene er hvor stor potensiell KILE det er for de ulike områdene.


Helsetilstand
Ha god oversikt over komponentenes helsetilstand og raten av degradering. Ut fra driftsrelatere data og miljø og andre faktorer.
For prioritering av vedlikeholdsarbeid er en god oversikt over konsekvenser, helsetilstand og kostnad interresant. (Hvilke komponenter må det følges med på)
Restlevetid på komponentene.
Få inn mulihetem for potensiell feil.
Bedre kontroll på holdbarhet på komponenter i ulike klima/ andre påkjenninger.
Bättre dataunderlag och analysverktyg för att avgöra när en komponent behöver bytas ut. För att minska risken att komponenter byts ut för tidigt eller för sent och att bedömningen görs mer systematiskt och likartat oavsett vem som gör det
Verktyg som underlättar att identifiera på ett tidigare stadie vilka komponenter som kommer behöva bytas ut för att ha framförhållning i beställningar
Informasjon som kan tenkes brukt i forbindelse med en utregnet helsetilstand/ degraderingsrate
Observasjoner om nåtilstand, produsent, lot, materiale, estimertlevetid (fra produsent eller reliability database) eventuelle belastninger dersom dette påvirke levetid. Lokasjonsdata dersom levetiden påvirkes av dette lufttemperatur, vind nærhet til kyst (salt)
Helseindeks:
Få inn sannsynlighet for feil og konsekvens av havari
Bra metodikk smo ble vist i møtet i morges med risikobasert tilnærming
Program som GV som gir oversikt over feil som må prioriterast
Verktøy som forutser potensielle feil før det går galt.
Oversikt over anlegget:
Alder, oftere utfall, vegetasjon osv.
Deler som oftere må befares?
Forståelse av kva som kan stå og kva som må utbedrast

Feedback concept




Oi, her har det skjedd litt siden forrige befaring.
Hvor skal jeg starte..?
Hilde, kan du hjelpe meg å vurdere dette avviket?
Klart det!
Bør vi utbedre denne råtne tretraversen?
Nei, Her kommer det uansett ny linje om 2 år
Det tar sikkert 5 år..
Men du burde prioritere de isolatorene likevel
Matthias har nettopp mottatt en mengde data fra toppbefaring på et linjestrekk. Forrige toppbefaring på samme linjestrekk ble utført for 10 år siden.
Registrerer avvikene direkte i netbas. Hvor kritisk er dette? Vurdere opp mot tidligere observasjoner
Noe utsettes
Må tenke frem i tid for å sette i gang med utbedring
Må ta tak i noe, men hvis det f.eks kommer ny kabelforbindelser om 5 år gir det noen grenser for hvor mye han skal ta med.
Har han denne fremtidsinformasjonen tilgjengelig?
Mathias må vurdere funnene/avvikene opp mot forrige befaring/utvikling
(Tett oppfølging, gjerne årlig med drone)
Rådfører seg med Hilde
Må komme frem til å lage arbeidsordrer på det som skal utbedres
Sendes til de som skal utbedre
(hvis du får koblet ut uten å berører kunder så får du lettere gjort utbedringer.
Hva er mest lønnsomt - bytte hele traversen eller kun isolatorene?

14:25
(30 min)

Prototyping

Avvikene i kartvisning

(i dag: rapport, vurderer å sette i bestilling eller sette på vent)

Sunniva Jerndahl

Må kunne se funnene opp mot tidligere inspeksjoner

Se utvikling over tid

Sunniva Jerndahl

Bør også ha med fremtidig planlagt vedlikehold

Sunniva Jerndahl

Hva er forventet levetid på komponentet?

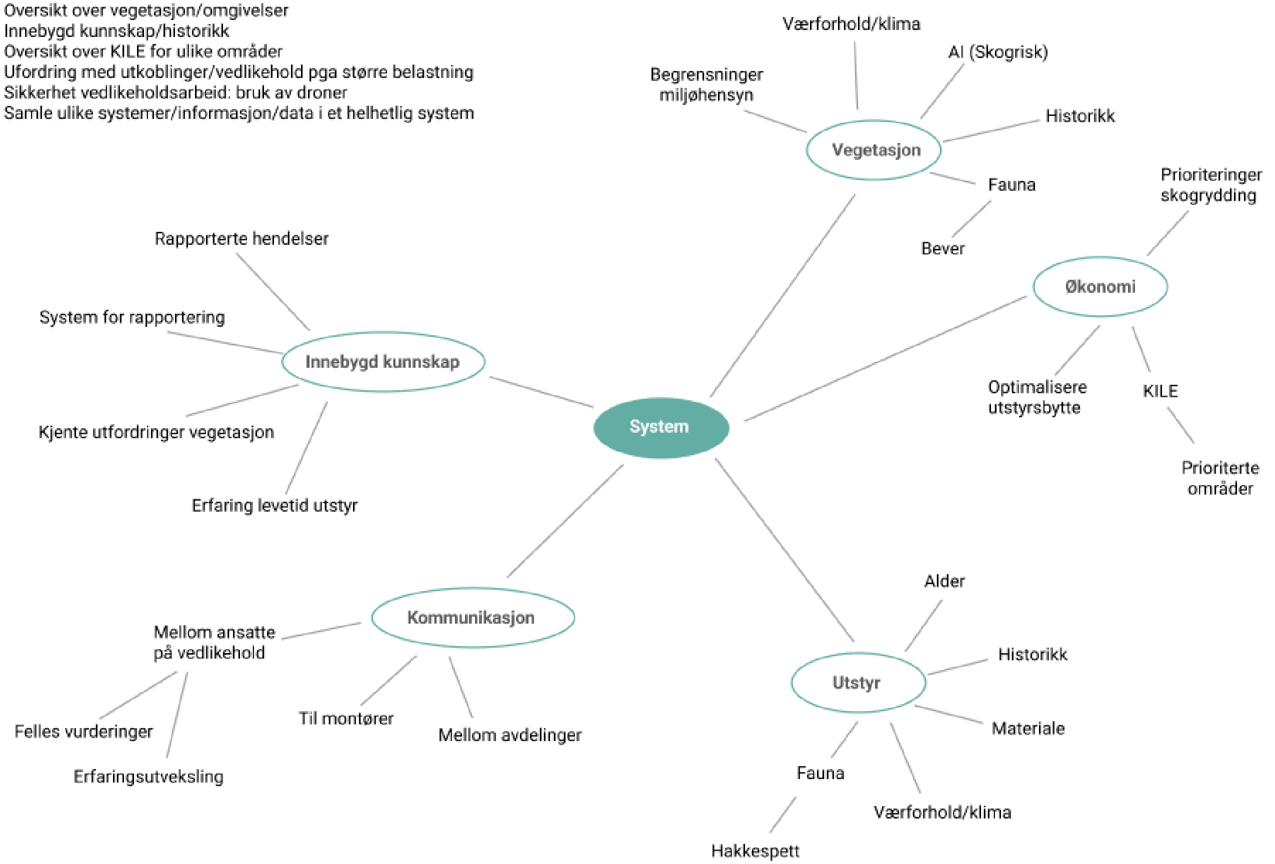
Sammenlignet med planlagte utbedringer i fremtiden?

Sunniva Jerndahl

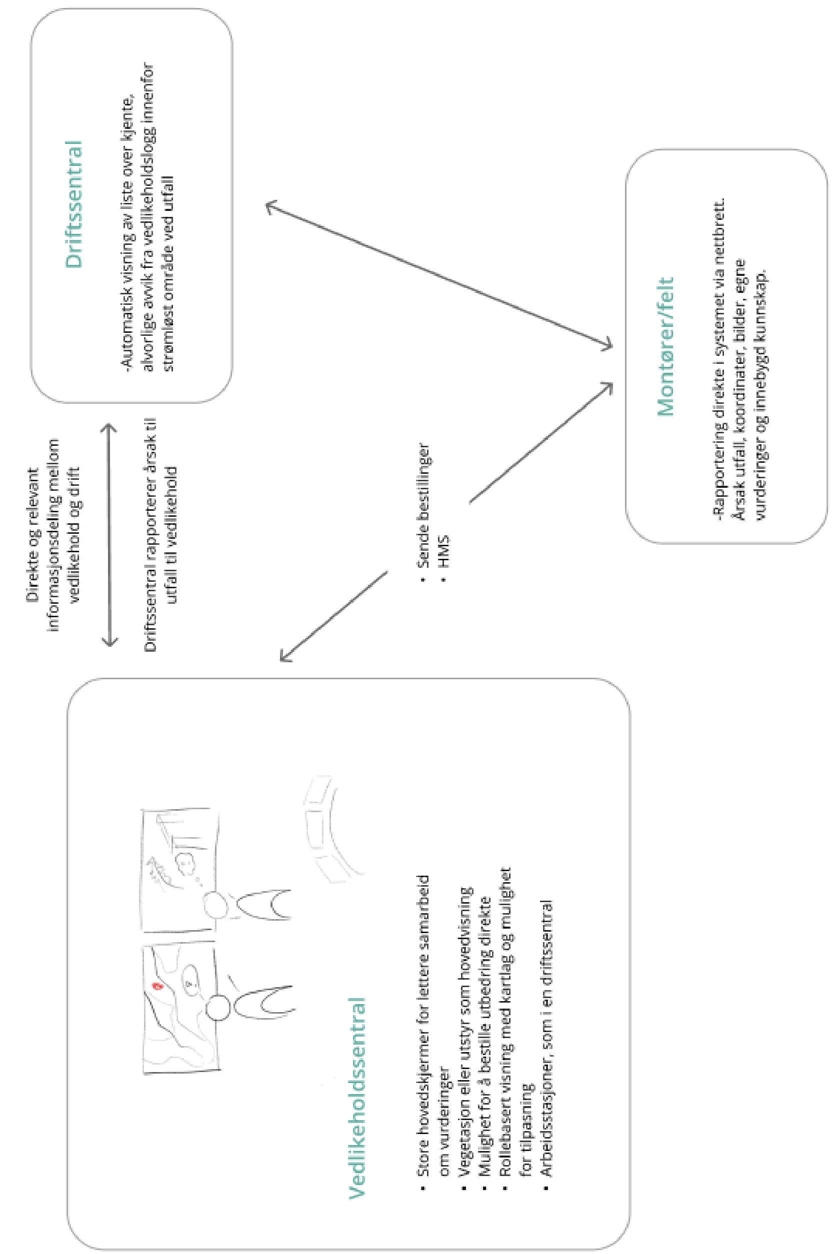
Information needs

Brukerbehov informasjon:

- Tilstand på komponenter/utstyr
- Oversikt over vegetasjon/omgivelser
- Innebygd kunnskap/historikk
- Oversikt over KILE for ulike områder
- Ufordring med utkoblinger/vedlikehold pga større belastning
- Sikkerhet vedlikeholdsarbeid: bruk av droner
- Samle ulike systemer/informasjon/data i et helhetlig system



Appendix E


Driftssentral
-Automatisk visning av liste over kjente, alvorlige avvik fra vedlikeholdslogg innenfor strømløst område ved utfall
Direkte og relevant informasjonsdeling mellom vedlikehold og drift
Driftssentral rapporterer årsak til utfall til vedlikehold
• Sende bestillinger
• HMS
Montører/felt
-Rapportering direkte i systemet via nettbrett. Årsak utfall, koordinater, bilder, egne vurderinger og innebygd kunnskap.
Vedlikeholdssentral
• Store hovedskjermer for lettere samarbeid om vurderinger
• Vegetasjon eller utstyr som hovedvisning
• Mulighet for å bestille utbedring direkte
• Rollebasert visning med kartlag og mulighet for tilpasning
• Arbeidsstasjoner, som i en driftssentral