UNIVERSITY OF AGDER

Application of Heavy Equipment Telematics in Infrastructure Projects

Method for automating collection of mixed fleet data, and optimization of projects through the use of telematics data

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Preface

The initial background for this research originated in my passion for technology. The construction industry is generally known to be lagging behind when it comes to technological advancements, and I saw potential to help improve it. During my time working summer jobs at Nye Veier I gained a more practical view of how infrastructure projects are carried out. Experience that would speak to me when offered the opportunity to write a thesis about heavy equipment telematics.

In all honesty, my work could not have been achieved without the support of other people. First of all, I would like to thank my supervisor, Paul. His enthusiasm for the project motivated and guided me along the way. Secondly, my contacts in Skanska, without whom I would be lost. Katrin and Astrid. Thank you for providing me with needed information and opinions along the way. And finally, my parents, who have shown me never-ending support throughout all these years.

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23.05.2019

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Abstract

Existing heavy equipment telematics capabilities are not being used to their potential. In collaboration with Skanska there is an interest to look at how telematics can be used more efficiently with mixed equipment fleets. Current and future aspects are compelling, especially in relations to optimization and environmental benefits. *Rv. 3 /rv. 25 Løten–Elverum* is provided as a case.
This master's thesis takes a closer look at the use of telematics data from heavy equipment at infrastructure projects. Through the automation of collecting telematics data, mixed fleet data are juxtapositioned to give insight into site activities. Literature reviews and tests show that data relating to fuel consumption, machine hours, productivity, and equipment location are central to optimization. Additionally, contractors can quantify their performances and environmental impacts to be applicable in procurement processes through the use of telematics data.

Keywords: telematics; heavy equipment; infrastructure; automation; optimization

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Nomenclature

Abbreviations

API	Application programming interface.
BIM	Building information model/modelling.
ISO	International Standard Organization.
LCA	Life Cycle Analysis.
PM	Particulate matter.

Glossary

Aggregate Functions	Functions that summarize multiple rows of a data table to a single value.
Fleet	The group of heavy equipment at a project.
Heavy equipment	Vehicles intended for construction work.
String	A sequence of characters.
Query	Data retrieval from a database.
NULL	Represents a value that is blank.

Symbols for chemical components

CO	Carbon monoxide.
CO_2	Carbon dioxide.
HC	Hydrocarbons.
NO_X	Nitrogen oxide.
SO_2	Sulfur dioxide.

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1 Introduction

The infrastructure industry is modernizing rapidly this millennium. There has been a surge of new tools both in the office and out on site. This rapid development makes it hard for contractors to keep up to date. While some see the potential for improvements through new technology, others might not reap the same benefits and fall at a disadvantage in a competitive market. Data from heavy equipment telematics is nothing new. It has been around for years already, but companies fail to see and adopt its potential.

1.1 Background and partner

On February 6th, 2017, Nye Veier and the University of Agder signed a cooperation agreement [1]. This lead to the *More Efficient and Environmental friendly Road Construction* (MEERC) research project, which is a *think tank* between academia and industry. It has two main goals. The first one is to assist *Nye Veier* in fulfilling its motto of *"building good roads fast and smart"*. Secondly, it is to improve the engineering education at the University of Agder. The intended purpose is that this will culminate in more road for the money, less pollution, and more innovation [2].
Skanska represents one of multiple participants from the industry in MEERC. As a major contractor in the Norwegian construction market they have felt an increased demand for environmental considerations in the construction procurement process. Being able to document activity will be important to secure future contracts. Skanska contributes with a proposed task and accompanying case. The proposal from Skanska was to look at ways of using data reported by heavy equipment telematics to achieve an increased understanding of logistics and pollution patterns [3]. In turn, the intended purpose will be to use the data for documentation of own activities, and to use it to acquire knowledge of processes in a way that makes for a better decision making in future projects.

This master thesis is a continuation of a preliminary report written during the fall of 2018 (Appendix B). The objective of the preliminary course was to prepare the student for the master's thesis by acquiring fundamental skills and knowledge about a subject. By studying the infrastructure project *Rv. 3 /rv. 25 Løten–Elverum* as a case, possibilities for further work through the master's thesis was explored. It was learned that the project had a fleet of mixed equipment where the majority of equipment came fitted with telematics. However, the use of telematics is up to each contractor and the current use is negligible. The nature of mixed equipment fleets are inconvenient in that the equipment only report to their manufacturer's telematics system by default. This is problematic when several equipment brands are involved and each contractor only have access to their own equipment data. It gives an inconvenient and incomplete picture of site activities when the data is spread out across multiple platforms. A lot of manual labour will potentially have to be made in order to collect and analyze the data sufficiently.
Through the preliminary study it became clear that the interest is at looking for ways of using existing telematics to improve current and future aspects of site operations. Preferably from an environmental and optimization perspective.

1.2 Problem statement

Existing heavy equipment telematics capabilities are not being used to their potential. On larger infrastructure projects there are generally multiple contractors and telematics systems involved. In collaboration with Skanska there is an interest to look at how telematics can be used more efficiently with mixed equipment fleets. Current and future aspects are compelling, especially in relations to optimization and environmental benefits.

2 Sociological perspectives

2.1 An environmental perspective

The climate on Earth has been varying throughout the planet's existence. There are a lot of variables at play in climate dynamics. Major factors include: which phase the sun is in, what time of the year it is, and the composition of the atmosphere. Scientists are now observing a rise in temperature that goes beyond what is to be considered normal. A study from 2016 found it reasonable to assume a 97 percent consensus among published climate research on humans as the cause of the recent global warming [4, p. 6].

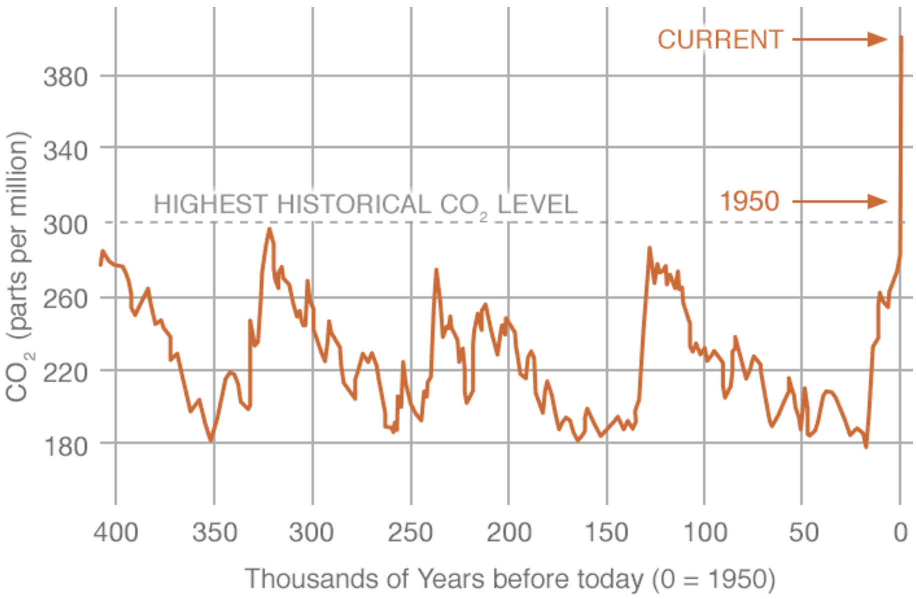


Figure 2.1: Reconstruction of CO_2 abundance in the atmosphere over the last 400 thousand years. Data from sampled ice cores [5].

One of the major factors at play in this human warming of the climate is the amount of CO_2 in the atmosphere. This greenhouse gas absorbs more of the energy from the sun, which in turn traps larger amounts of heat in the atmosphere. By measuring CO_2 contents in ice-cores dating as far back as 400 thousand years, scientist are able to create a model of how CO_2 abundance in the atmosphere has evolved over these years (Figure 2.1). The amount of CO_2 in the atmosphere is shown to be much higher than trends would implicate, and it is viewed upon as the biggest human contribution to the warming.

On April 22, 2016, the *Paris Agreement* officially opened for signature [6]. The agreement works to combat climate change by requiring participating countries to limit their greenhouse gas emissions. The target is to keep the global temperature rise of this century below 2.0 °C, preferably limiting it to 1.5 °C. As of March 2019, Norway is one of the 195 countries that have signed the agreement [7]. A commitment to the Paris Agreement can be seen in the Norwegian *Climate Law* from January 1, 2018. It states goals of reducing greenhouse gas emission by 40 percent within 2030 compared to 1990, and 80 to 95 percent by 2050 [8, §1-4].

This trickles down into the Norwegian *National Transport Plan*. The plan states the goals and principles of the Norwegian government in regards to transportation, over a period of 12 years. The current plan for 2018-2029 aims to reduce emissions during the construction of infrastructure projects by 40 percent within 2030, compared to 1990 [9, p. 243]. This will be achieved through increased use of zero emission technology, alternative fuels, and conscious choices on materials and material amounts.
Statistics Norway (SSB) categorizes heavy equipment as *motorized equipment* [10]. This category was responsible for a 2.8 million ton CO_2 equivalent emission in 2017, which approximates to 5.3 percent of the total [11, Table 3]. This is an increase of 45 percent for motorized equipment compared to 1990 [11, Table 5].

2.1.1 International consequences

As further emissions of greenhouse gases will contribute to more warming, it will create new risks and amplify existing ones. The effects and severity will depend on geographical location, according to the *Intergovernmental Panel on Climate Change* (IPCC) [12, p. 13-14]. Many species will have an increased risks of extinction. In most landscapes, plants will not be able to move to suitable geographical locations quick enough as the climate changes. Wheat and rice are are among those who will suffer in temperate and tropical regions. The same goes for many animals, and these predictions will in turn have severe negative effects on local food production.
In the ocean there will be increased acidification because of increased absorption of CO_2 from the atmosphere. Consequences are already witnessed today with coral bleaching, and it is expected to impact a wide range of marine organisms and ecosystems. Lower oxygen levels in the sea will also contribute to harsher conditions. In turn this will affect fisheries and aquaculture. Coastal and island regions can expect loss of livelihood as the ocean level increases. According to NASA the sea level had risen 90 (± 1) millimeters by November 2018, as opposed to 1993 levels [13]. This is caused by meltwater from large glaciers and the polar ice caps seeping into the world ocean.

An important distinction to make is how detrimental a global temperature increase of 2.0 °C is compared to 1.5 °C. The IPCC predict several effects based on their latest assessment report [14, p. 177-181]. For some parts of the world it is projected that a 2.0 °C warming will have a 2-3 times greater means and extremes than a 1.5 °C increase would have. The projected threats associated with water availability are among the risks that will be greatly reduce by limiting the global warming to 1.5 °C. There is high confidence that a warming of extreme temperatures will occur in several regions. There will occur more warm extremes and less cold extremes, where the colder extremes will be warmed the most. Limiting the temperature increase to the minimum extent possible is important.

2.1.2 National consequences

The *Norwegian Environmental Agency* make several predictions for the climate in Norway leading up to the year 2100 [15, p. 6-8]. This report points to an increased annual temperature of 4.5 °C. While the largest increase will be seen inland, it will be the lowest by the coast. It will rain more often and in larger amounts at a time. More floods and landslides will occur because of this. Increasing ocean levels are expected to be largest in the south and west. This could prove to be problematic for coastal cities like Oslo, Kristiansand, and Trondheim.
There are several consequences of climate change on fauna [16]. Several species are threatened by extinction, especially those living in arctic and alpine environments. Species that prefer warmer climates will have a better premise for survival and move into regions once

inhabited by those who prefer it colder. This will change the natural composition and bring about unpredictable change as previously unseen species enter habitats.

2.2 An economical perspective

Public infrastructure is the responsibility of the Norwegian government. The construction, operation, and maintenance of such projects is financed through government grants and tolls. By optimizing aspects of these projects there is money to be saved. Better technical solutions will result in cost-savings, that in turn gives society better value for its money. In 2016, the chief executive of Nye Veier stated that the estimated price of a project at the time had been reduced from 5.5 billion Norwegian kroner (NOK) to 5.0 billion NOK [17]. That is a reduction of 9.1 percent, and it will benefit the drivers through less tolls.

3 Theory

This chapter presents the theoretical background of the thesis. It is important to understand how heavy equipment telematics and relevant software function. In addition, it is relevant to explore the knowledge front surrounding the application of telematics in infrastructure projects.
The fundamentals of heavy equipment and telematics were explored during the preliminary (Appendix B). Relevant theory has been included to present a more comprehensive understanding of telematics in this report.

3.1 Heavy equipment

Heavy equipment refers to vehicles that are designed to perform construction work. Types of such equipment include:

- *Articulated truck*: A large dump truck that is typically used to carry loads from one place to another. This distance often involves the transversal of rugged terrain, and public roads from time to time.
- Bulldozer: These vehicles have continuous-tracks and are equipped with a large plow up front. They are used to push and distribute mass that is in front, to even out the materials on the ground.
- *Excavator*: Vehicles that are equipped with a hydraulic arm as their primary tool. The tip of the arm is typically equipped with a bucket which is used to lift and excavate mass. On infrastructure projects it is often teamed up with articulated trucks to both excavate and move mass over distances.
- *Wheel excavator*: Essentially an excavator equipped with wheels, instead of than being continuously tracked.
- *Wheel loader*: Vehicles whose typical functions are to load materials onto other equipment, and to even the ground. Often equipped with a bucket in front, and used to load an articulated truck.

All modern heavy equipment come with telematics in some form. Cat and Volvo are the more popular heavy equipment manufacturers in Norway. They have supplied telematics for their heavy equipment for years.

3.1.1 Emissions

A vast majority of heavy equipment today run on diesel as their fuel. Exhaust emissions from diesel include CO, CO_2, NO_X, SO_2,and PM. While the primary concert with CO_2 is its warming of the climate at a global scale, the other emissions are more of a concern to local air pollution [18]. Stricter emission standards have been issued that limit the amount of emissions permitted from engines. For non-road vehicles the emission standards are called *Stages* in Europe. The latest being *Stage V* [19]. While equipment using hybrid fuels are currently seen as the most viable way to reduce fuel emissions, fully electrical equipment are slowly becoming viable too. In 2018, *Pon Equipment* launched the first fully electrical 25 metric ton excavator [20].

3.2 Telematics systems

Telematics is a term used to describe integration of vehicle monitoring systems by wireless communication. Such data is collected by sensory in the equipment and communicated by cellular network and GPS. The exact data depends on the equipment model and what telematics unit the machine is equipped with.

3.2.1 Telematics API

An Application Programming Interface (API) is a software that enables two applications to communicate. For telematics systems that have this service enabled it means that information can be pulled directly from the manufacturers database and to the client application [21, p. 2].

3.2.2 ISO 15143

ISO 15143 is the standard for heavy equipment telematics. There is a certain standard for what parameters are recorded and reported, thanks to the ISO 15143. The standard is the work of the *Association of Equipment Management Professionals* (AEMP) [22]. They brought together heavy equipment manufacturers and telematics providers to develop the first telematics standard for the industry. *Caterpillar* (Cat) and *Volvo Construction Equipment* (Volvo CE) were among the manufacturers that supported such a standard [23]. The resulting standard states that telematics data is to be standardized across manufacturing brands. At the moment it consists of three parts, with a fourth being under development [24]. Up until recently, the heavy equipment manufacturers were the sole providers of telematics data. This has however changed with the introduction of the ISO 15143-3 standard.

The ISO 15143 standard consists of the following parts:

- ISO 15143-1, *System architecture*: Establishes a system for easy and reliable exchange of data between equipment and systems. From equipment to information system, and information system to contractor. The system is however not applicable for exchange between contractor and project owner [25].
- ISO 15143-2, *Data dictionary*: Defines the data being exchanged. It identifies which data is to be exchanged, their specifications, and format. The standard applies to equipment on typical construction sites [26].
- ISO 15143-3, *Telematics data*: This part specifies the extraction of equipment data from manufacturer to third-party telematics providers through the use of API. This is intended for the convenience of mixed fleet of equipment. Data can be queried directly from the equipment database by accessing the manufacturer data through the API. This part is intended to be used in conjunction with part 1 and 2. It provides directions for the format of data transmitted by API, and how certain parameters are to be cumulative in nature. Central data parameters are defined by the standard to help mixed-fleet management. Among these are serial number, asset ID, hours, location, distance travelled, fuel consumption, idle time, and payload totals [27].

3.2.3 CareTrack

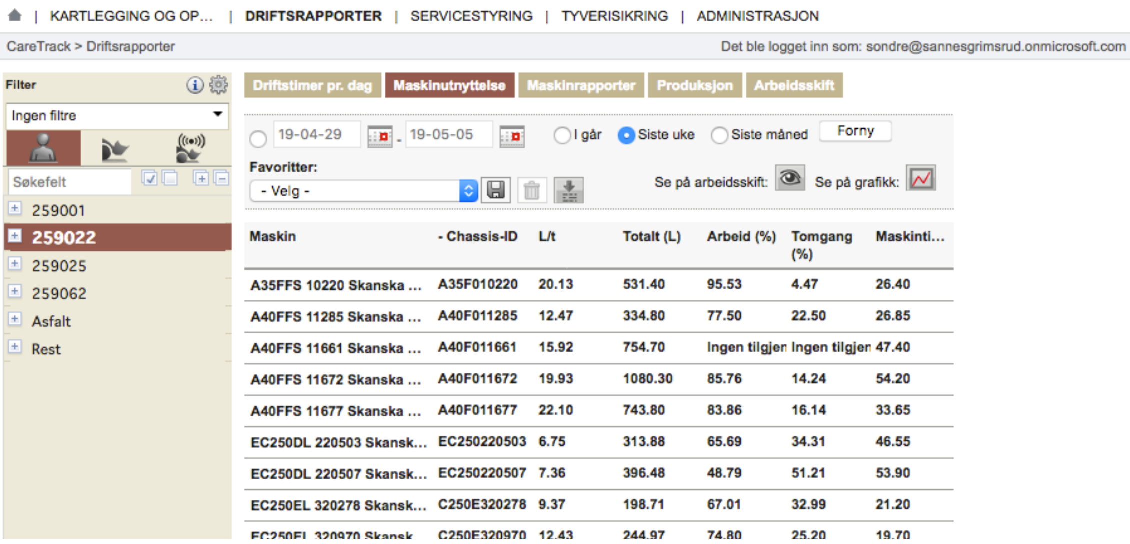


Figure 3.1: A view of the CareTrack web application interface [28].

CareTrack is the telematics system developed by Volvo CE (Figure 3.1). It is a web interface for telematics information, and provides standardized ISO 15143 parameters as well as additionally calculated parameters. It provides an interface for the data sent by equipment with telematics capabilities. CareTrack is divided into several modules that provide a certain set of equipment parameters. Which equipment and data that appear in each module depends on the active subscription of the equipment, and what telematics capabilities the equipment itself has. Newer equipment come equipped with better telematics opportunities.
Volvo Maskin AS is the dealer of Volvo CE equipment in Norway. They supply CareTrack at a monthly cost for each equipment, with additional costs for each module. The *Operation reports* module gives parameters about fuel consumption and machine hours. The shortest time interval for such reports is one day, and the longest is 125 days. Data older than 400 days is not available.

According to Volvo Maskin AS, their equipment sends data from the previous day when it is turned on. CareTrack allows for e-mail subscription to equipment reports daily, weekly, and monthly. These reports can be set up for a group of chosen equipment, and it will be sent to the users registered e-mail as an attachment. Depending on what kind of module you subscribe to you can receive the report either as an Excel file or as a PDF. Data in these reports gives parameters for each equipment chosen and it appears cumulative for the period chosen. There is also functionality for manually generating a report for a chosen interval of dates.
Visualizing data in CareTrack can be done by bar charts of a requested period. There is generated one chart for each equipment selected, and they show the sum of total liters fuel consumed over a selected period of time.
As CareTrack has adopted the the ISO 15143-3 standard, and provides API capabilities.

3.2.4 VisionLink

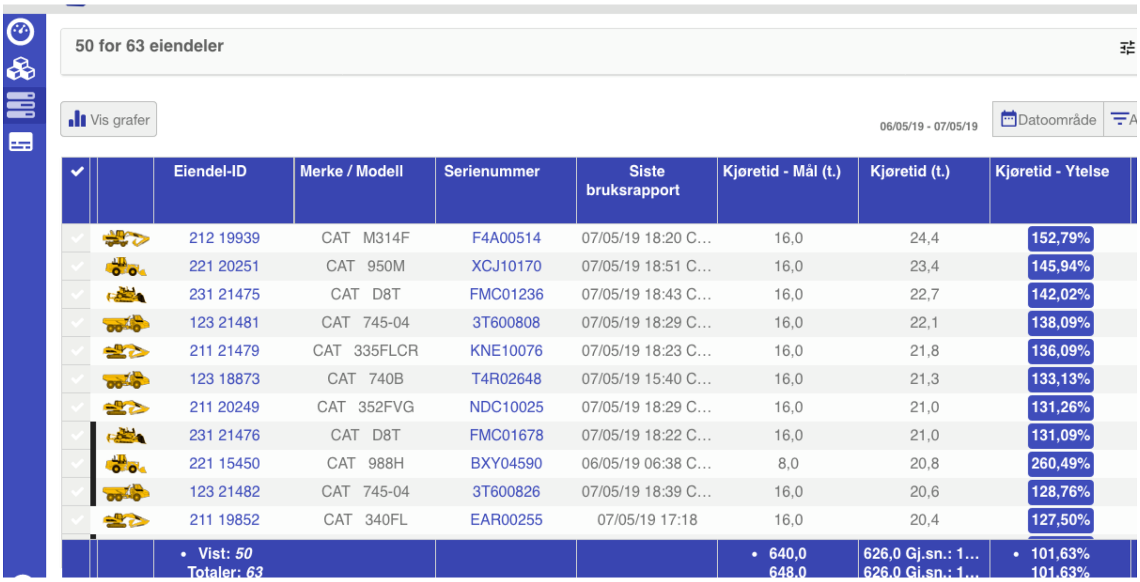


Figure 3.2: A view of the VisionLink web application interface [28].

Cat has developed VisionLink as its web interface for heavy equipment telematics (Figure 3.2). It provides ISO 15143 standard parameters, as well as other calculated parameters. It is divided into multiple modules depending on what kind of equipment data is needed. Available equipment in each module depends on what telematics capabilities each specific equipment is equipped with.
Pon Equipment is the provider of Cat equipment in Norway. They provide multiple subscriptions for modules at different costs. The *Unified Fleet* module provides parameters about fuel use, machine hours, distance driven, and location of the equipment. *Unified Productivity* provides parameters related to payloads. Available data is from 13 months back in time and up until the current date. VisionLink also provides the ability to manually pick an interval of dates that you want to generate a report from.

Pon Equipment have stated that their equipment is set to report once a day by default unless otherwise is requested. This is because their costs related to transmitting data being related to amount and frequency. E-mail subscription to module specific reports are available at daily, weekly, or monthly intervals. The e-mail provides a direct link to the report file to be downloaded. Reports contains data from equipment that has been specified, and can be either an Excel file or in the *comma-separated values* (CSV) file format.
VisionLink allows visualization of the data through bar charts. These charts set the equipment up against each other, and they can be based on several of the most common equipment parameters. A period of time can be applied to the charts.
VisionLink has adopted the ISO 15143-3 standard and provides API capabilities. It also has the ability to display information from third-party equipment manufacturers and telematics hardware makers [29].

3.2.5 Third-party telematics providers

There are third-party providers of telematics that are not affiliated with the equipment manufacturers themselves. The third-party providers supplies software that gathers data through the manufacturer API, or provide it through their own hardware installed in the equipment. These solutions are generally targeted at mixed fleets.
TrackUnit is a company that delivers such capabilities [30]. They offer possibilities around installing hardware that generate the data, or by accessing the manufacturer API through their software solutions.

3.2.6 Geo-fences

Geo-fences are the creation of a geographical boundaries by GPS location. An area can be defined, and equipment is registered when it is inside or outside the virtual area. Further actions can be applied to equipment based on their status with the area. CareTrack and VisionLink both supply this functionality.

3.3 Telematics fleet data

3.3.1 Optimization

Optimization of work sites can be achieved by applying telematics to a fleet of equipment. More efficient use of equipment will lead to reduced profitability. Applying and using telematics on an equipment fleet can increased performances, reduce costs, and in general provide trends based on data from the site. Parameters relating to the following data are viewed as valuable aspects of heavy equipment optimization, and it is the overall impression from several sources [31, p. 5] [32, p. 794-795] [33, p. 44]:

- *Equipment hours*: Parameters related to the hours a machine has operated can be used for better management that will reduce costs.
- *Equipment location*: Enables accurate allocation of other data to a location. The utilization rate of equipment in areas can be monitored.
- *Fuel consumption*: Data about fuel consumption can be used to identify where and when fuel is wasted. Application and operator issues can be uncovered by this kind of data.
- *Productivity*: Can be increased through identifying and eliminating inefficiencies of activities. Mass excavated and moved can be measured and recorded. Learning from the data can provide more efficient site operations for contractors. Equipment under-utilization can be identified, and uptime can be improved.

3.3.2 Idling

The amount of idling is regarded as one of the more sought after information from heavy equipment. When the equipment is registering its engine as performing idling depends on what vehicle it is and its configuration. Monitoring equipment idling is viewed by many as one central way of optimizing a fleet. Reducing the amount of idling will benefit the environment and contractor through less emissions and fuel use.
Maskinentreprenørenes Forbund (MEF) states that spending 30 to 50 percent of the work day idling is not unusual for heavy equipment [34]. They have arranged for a competition regarding idling during the second half of 2019. The aim is to see which competitor that can reduce their idling amount by the most.

A similar approach to incentivize lower idling was taken in 2013 by *Heldal Entreprenøren AS* [35, p. 31-33]. They arranged for an idling competition internally by publishing the monthly idling amounts of each heavy equipment at the case in the construction barracks. A prize was given to the operator with the best results. They claim to have reduced the idling by 13 percent on average, and that cuts of around 14 000 NOK per year in diesel for a heavy equipment is not unrealistic.

3.4 Procurements

3.4.1 Public procurements

The law of *Public Procurements* (Anskaffelsesloven) is intended to promote efficient use of resources from society. It applies to all contracts that equal or exceed 100 000 NOK [36, § 2]. In practice this means that all infrastructure projects with a large heavy equipment fleet are bound to follow this law. The law states that all public procurements will involve a tendering process.
Anskaffelsesloven was updated in 2017. It now also states that the public procurement practice must be aligned towards promoting climate-friendly solutions, and the reduction of harmful environmental impacts [36, § 5]. The employer must do this by taking the life-cycle costs into account, in addition to other things. As long as it involves the delivery, an employer is free to produce suitable criteria and requirements throughout the procurement process. This is as long as it promotes considerations towards the environment and innovation.

The *Agency for Public Management and eGovernment* (Difi) gives directions to the public sector as a driving force to achieve quality and efficiency through change and renewal [37]. If environmental considerations are central to a procurement, Difi states that it is recommended that environmental requirements are established [38], and that there are clearly defined environmental properties. It is stated that if the environment is considered an award criteria it should be weighted at minimum 30 percent to exhibit importance.
If the cost of environmental impacts can be calculated, Difi states that it can be included as a life-cycle cost [39].

3.4.2 Best value procurement

The *Best Value Procurement* (BVP) method is intended to ensure that the most suitable contractor is picked for the job [40]. It requests documentation that is specific and fact-based throughout the execution phase. Quality and competence is favored over cost as an award criteria. What project goals are emphasized in the procurement is up to the employer to define.

Based on experience from two pilot projects, Nye Veier has started the procurement process for two new pilot projects along E39. The projects are *E39 Kristiansand vest - Mandal øst* and *E39 Mandal øst - Mandal by*. Both projects have a goal that states the following, "Minimize greenhouse gas emission and other loads on the external environment" [41].

3.5 Application software

3.5.1 Office 365

Office 365 is subscription based services provided by Microsoft [42]. Its subscription plans are set up and intended for different uses, and they offer the access to a variety of software depending on the subscription type. Several of the services provided offer options for collaboration and teamwork.

3.5.2 Power BI

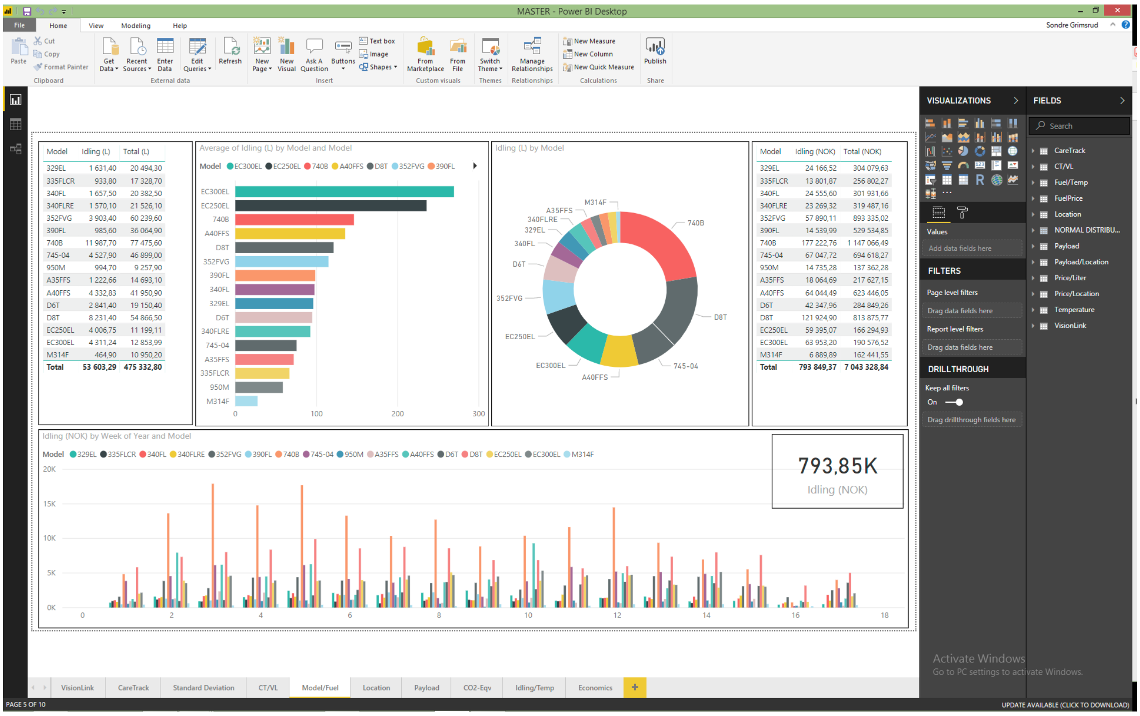


Figure 3.3: A view of the Power BI interface [28].

Microsoft Power BI is a Office 365 software intended for business analytics [43]. It supplies ways of visualizing and analyzing data, and to later share the results in the Office 365 environment (Figure 3.3). Power BI operates by loading and processing data from a wast area of sources.
There are two ways to use Power BI:

- Power BI Desktop: This version is free. It is used for creating interactive reports from defined data sets. It is the desktop version of the software, and installed as software on your computer. Power BI Desktop is used to structure the loaded data into data sets, and then perform analysis on the data set. This is done by applying one of the multiple way of graphical rendering to the data.

- Power BI Pro: Is a service that enables the sharing of the interactive reports created with Power BI Desktop. The reports and their data sets are uploaded from the desktop version can be handled further in this web application. Power BI Pro is primarily intended for applying visuals to the data in a collaborative environment.

Power BI also comes packed with several visualizations from third-party. One of these is the Power BI verified *ArcGIS* map [44]. It maps values to geographical locations by applying size and color to the data. This helps analyze the values in a geographical context.

3.5.3 SharePoint

SharePoint is a Office 365 cloud-service supplied by Microsoft. It is primarily used to store data and for document management. It supports functionality for collaboration across teams and organizations [45].

3.5.4 Flow

Flow is a Office 365 online service for automating work [46]. One of its features is to automate work related to e-mails. Flow can be configured to be triggered by certain incoming e-mails. When triggered it acts on the content of the e-mail in a pre-programmed way. One way it can be configured is to save the e-mail attachment to a folder in SharePoint.

3.5.5 Parserr

Parserr is a verified connector to use with Flow [47]. It is used to extract data and information from e-mails in an automated fashion. It then parses the data to another source. The monthly fee is free for a maximum of 15 e-mails a month [48].

3.5.6 appear.in

appear.in is a web application for video meetings [49]. It can be used both from computers and mobile devices through their web browser.

3.6 Big Data telematics

Big data is a term that labels extreme volume, velocity, and variety of data [50, p. 10]. It is essentially the concept of handling large volumes of different data. It is important for being able to gather and control at a larger scale. Analyzing such data quantities can be time consuming, but make impacts to the outcome of business.
When operating with telematics on the scale of large fleets one should consider applying a Big Data mindset [51]. Data collection from a large quantity of equipment over time can be related to Big Data, as data from fleet activity can produce problems when it comes in greater volumes. Using Excel sheets for analytics will simply not be practical and doable at the larger scale that fleet telematics require. It is important to take a broad look when deciding what data to collect, as the equipment manager will not sit on the data for an extended period of time. You can not go back to collect it after a certain time.

3.7 BIM-kiosks

The implementation of BIM-kiosks at the site have proven to be a valuable asset for workers in construction projects. *Statsbygg* and Skanska conducted a research project in 2016, where one of the subjects was to look at the use of BIM-kiosks on-site [52]. Workers experienced a more comprehensive understanding of the work when it is visualized. It also contributes to a greater sense of cooperation and problem solving aspect between the workers. This was because they meet at the kiosks to discuss problems through the model.

3.8 Theory of method

This sub-chapter is intended to look at the theory of different methods that have been used. It will give insight into why certain methods are used by looking at what results the different methods are intended to achieve.

3.8.1 Literature review

A *literature review* is a tool to gain knowledge from existing literature on the topic. By consulting existing literature you gain a theoretical perspective of the topic, which in turn acts as a foundation for further knowledge. By looking at the grander scheme of things you gain a better perspective of things. The method is intended to give a broad overview of current knowledge in a particular field.

3.8.2 Quantitative research

Quantitative research is an objective approach to investigations. The deduction of data from a larger number of cases with the intention of acquiring a basis for recommendations. The data is measurable and statistical in nature, and data analyzing methods applied are mathematical and statistical.

3.8.3 Interviews

Interviews are a method for gaining qualitative knowledge by consulting the knowledge of others. Interviews can be divided into three formats:

- *Structured interviews* have a fixed set of questions that have been determined beforehand.
- *Unstructured interviews* are informal in nature as questions are not prepared before the interview. Different formulation of questions can make answers hard to compare.
- *Semi-structured interviews* are a combination of both structured and unstructured interviews. These types of interviews come with a set of prepared questions, as well as the options for adding additional questions during the interview.

3.8.4 Case study

Case studies are a type of research method that takes an in-depth look of a subject. It is used to analyze certain issues related to a situation. Case studies are an advantage because they enable the capture of real-life complexities one would otherwise not be able to get.

3.8.5 Experiential learning

Experiential learning is a method where learning is done through experience. New experience is gained through interaction and observation. The new experience is then converted to knowledge by being reflected upon. This method is essentially the process of learning for the individual.

3.8.6 Trial and error

The *Trial and error* method is intended for problem solving. Varied attempts are made repeatedly until you succeed or stop trying. Most of the time it is used as a last resort, but it can be given a methodical approach to which there is a systematic thinking behind the attempts.

3.8.7 Timetables

Timetables are a time-management tool that apply a fixed timeline to work, actions, and occurrences. The table is layed out in such a way that events are chronologically ordered by dependencies on each other, and at what time they need to be finished. Timetables are used for making the best use of time.

4 Research questions

As a background, the preliminary report focused heavily on acquiring basic information and understanding of heavy equipment and telematics at the case. New research questions will have to be asked in order to answer the new problem statement of the master's.
To instigate a process that will give answers to the problem statement (Chapter 1.2), the following research question and sub-questions are asked:

1. **In what way can data from the heavy equipment be collected more efficiently?**
    a. To what degree can the data collection process be automated?
    b. Can mixed fleet telematics be a collaborative effort?
2. **What uses can be made of the telematics data from Rv. 3 /rv. 25 Løten-Elverum?**
    a. What optimization aspects are there?
    b. What environmental aspects are there?
    c. In what ways can heavy telematics be of assistance on site?
3. **How can heavy equipment telematics be of use to future procurements?**
    a. Can equipment data be used for documentation?
    b. What telematics data are relevant for future procurements?

4.1 Limitations and boundaries

Seeing as there is a limited amount of time, and having the resources of a sole writer, some limitations will have to be applied to the research questions. To make the research question more manageable to overcome, the following limitations are made:

- The telematics data is limited to Rv. 3 /rv. 25 Løten-Elverum.
- To illustrate a mixed equipment environment the thesis will look at Skanska's Cat and Volvo equipment at the case.
- The thesis is limited to earth moving equipment. This is because the available equipment at the case are earth moving equipment.
- The data time period will be limited to somewhere between the start and the end of the thesis.
- Data collected will be related to look at utilization and productivity of heavy equipment.
- The maintenance and service aspects are neglected, as this is familiar functionality to Skanska.

5 Case: Rv. 3 /rv. 25 Løten–Elverum

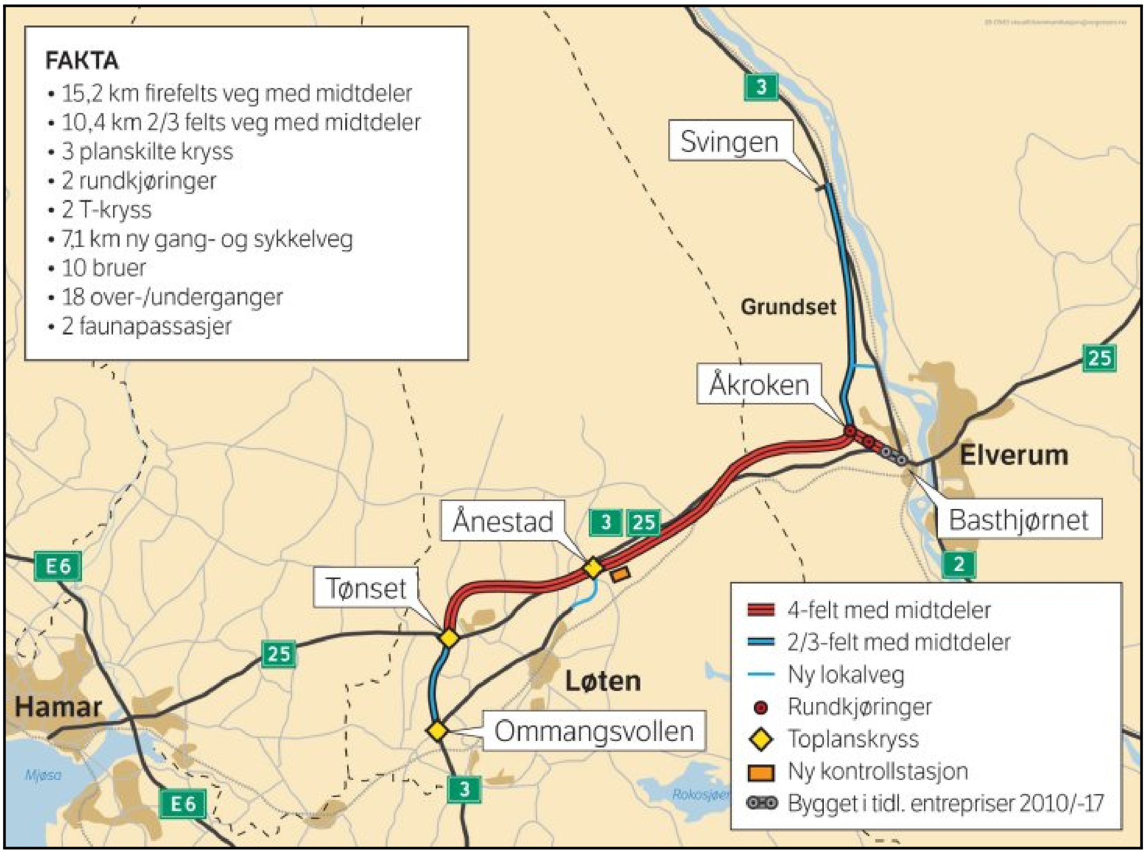


Figure 5.1: Illustration of what is to be built during the Rv3/Rv25 project [53].

In the spring of 2017, the *Norwegian Public Roads Administration* (SVV) issued a *public–private partnership* (PPP) contract for *Rv. 3 /rv. 25 Løten–Elverum*. The project is located just outside Elverum in Hedmark, Norway. After competing with multiple other firms in a tendering process, Skanska was awarded the contract in Mars 2018. Work started in June 2018, and the project is set to be finished by November 2020. After that, *Hedmarksvegen AS* will take care of the future aspects related to operation and maintenance for the coming 20 years [53].

The project will build 26 kilometers of road in just over two years. It involves 15.2 kilometers of four-lane road, and 10.4 kilometers of 2-3 lanes (Figure 5.1). Approximately 30 constructions are to be built [54]. As of February, 2019, there were around 350 workers on a payroll for the project. These numbers are varying from week to week as staffing needs fluctuate by activities. With a price of 5.5 billion NOK, it is the biggest contract issued for a infrastructure road project in Norwegian history at the time of writing [55].

5.1 Low utilization of heavy equipment telematics

The steadily increasing focus on telematics from the market has intrigued Skanska. They see more potential in the data than the current use would suggest. Through the preliminary case study it became evident that there is a wide range of equipment with telematics capabilities that has been available for some time, but neither Skanska or the other contractors uses them. After meeting with the fleet manager at the case, it was made clear that the current use at the case is limited to some minor maintenance aspects.

5.1.1 Rudimentary telematics interfaces

The CareTrack and VisionLink web interfaces offer little functionality when it comes to visualizing equipment data. There is considered little use of them because of the limited amounts of work that can be done in the web applications themselves.

5.1.2 The inconvenience of a mixed equipment fleet

Figure 5.2: Photo taken at the case. The image shows one of Skanska's Volvo articulated trucks working together with a Cat excavator from Vassbakk & Stol [56].

There are multiple contractors and equipment manufacturers involved at the case (Figure 5.2). Skanska has hired several sub-contractors to help see the project through. Other equipment at the project belongs to *Vassbakk & Stol*, *Gjermundshaug Gruppen*, *TT Anlegg*, and *Lundteppen* (Appendix D). There are two major inconveniences with this. The first one is that each contractor have their own systems of telematics for their equipment, and there is no collaborative effort made between them. Secondly, that each contractor has a telematics system for each brand of equipment they use. Collection sufficient amounts of data manually is inconvenient. Even if the telematics systems are set up to automatically report to the owners e-mail, the attachments still have to be downloaded manually. There are potentially thousands of documents that need to be processed and have their data extracted.

5.2 Available equipment

Skanska supplies a user account for both the CareTrack and VisionLink web applications. This gives access to data from Skanska's equipment at the project, as well as equipment at several other projects.

Table 5.1: Skanska equipment available in CareTrack and VisionLink as of 10.01.2019. They were located at the project.

Heavy equipment model	Equipment manufacturer	Quantity
Articulated trucks		**13**
- 740B	Cat	5
- 745-04	Cat	4
- A35FFS	Volvo	1
- A40FFS	Volvo	3
Bulldozers		**6**
- D6T	Cat	2
- D8T	Cat	4
Excavators		**9**
- 329EL	Cat	1
- 335FLCR	Cat	1
- 340FL	Cat	1
- 340FLRE	Cat	1
- 352FVG	Cat	2
- 390FL	Cat	1
- EC250EL	Volvo	1
- EC300EL	Volvo	1
Wheel excavators		**1**
- M314F	Cat	1
Wheel loaders		**1**
- 950M	Cat	1
Sum		**30**

From Cat and Volvo, Skanska has a total of 30 heavy equipment at the case which has telematics activated (Table 5.1). There are six Volvo vehicles and 24 Cat vehicles.

Skanska has operation reports and API enabled on their Volvo equipment. This is active on all six of the heavy equipment. All 24 Cat heavy equipment register to the United Fleet module, but only five of them have capabilities for reporting to the Unified Productivity module. Those are one 390FL excavator, three 745-04 articulated trucks, one 950M wheel loader. CareTrack has no heavy equipment with an active Production subscription.

5.2.1 Idling

Appendix E represents an internal mapping of the different idling and automatic stop criteria for equipment at the case. The first table states criteria that has to be fulfilled for a certain equipment type to register idling. The second table explains which criteria have to be satisfied for an automatic stop of the machine to occur. All heavy equipment at the project is configured to stop after five minutes of fulfilling the automatic stop criteria.

5.3 Feedback

Feedback regarding the case was received during the writing of the thesis. The following notes are a summary from different through interviews with Skanska:

- Weekly reports are the preferred interval.
- Heavy equipment operators work on shifts of 14 days on, followed by 14 days off. Change from one shift to the other occur on Wednesdays.
- Interest in idling and capacity to see trends. This is to see the optimization rate of the machines.
- Identifying equipment with high amounts of idling.
- Both Cat and Volvo equipment have been configured for a auto shutdown after 5 minutes at the project.
- Fuel is not bought at a fixed price.
- Vassbakk & Stol uses TrackUnit for their heavy equipment. It is used to track equipment locations and service intervals. They do not use the manufacturer telematics systems because of the fees involved with them.
- There is a suspicion that worker idle more in the winter to keep warm.
- The heavy equipment is configured to report their data during engine warm-up in the morning.

5.4 Assumptions and simplifications

Some values are not given, and have therefore been assumed:

- The vast majority of heavy equipment at the case use diesel as fuel. To simplicity the case it is assumed that all heavy equipment use regular diesel.
- Average weekly temperature at the site is taken from the *Yr* weather service [57]. Location assumed to be equal to that of Elverum city.
- After asking my contacts in Skanska. Fuel price per liter of diesel, based on monthly average retail price from SSB [58]. No value for April at the time of writing, so price assumed to be 15.00 Norwegian Kroner (NOK).

6 Method

To acquire the necessary knowledge to answer the research questions (Chapter 4), there were applied several methods. This chapter will walk through the applied use of the methods.

6.1 Literature review

There were several approaches taken to acquire research information related to the use of telematics with heavy equipment fleets, and different software solutions.

6.1.1 Existing literature

I searched existing literature on the subject. Student papers, journals, books, and manuals. The topic of this thesis is somewhat new and because of this, and in lack of available physical literature, extensive use of the world wide web was done to find this information.

6.1.2 Interviews

Key persons were consulted because topic is relatively new. Different kinds of interviews were conducted along the way, depending on what information was needed.
The study was mainly conducted through structured interviews / Surveys of personnel working on the project. In the surveys I pitched ideas to personnel of different positions, and the goal was to learn what was thought of my ideas and if they could provide thoughts for improvement and insight into what was really needed.
During the work of this thesis I received feedback through structured, unstructured, and semi-structured interviews. The feedback was taken into account and used to alter the project if adequate and fitting.

6.1.3 Observation and case study

Individual learning was done as a way to acquire information about how to use the web- and software applications there were used multiple methods depending on the application.

For the Office 365 applications the majority of learning was by reading guides on the official Microsoft learning pages for the software. Another much used method was to observe private persons exercise their knowledge of the software by video tutorials. Other than that there were a lot of *trial and error* and *experiential learning* along the way. Microsoft forums were also consulted for relevant topics on problems that were experienced with the software.
Leaning how to use the telematics systems was done mainly through *experiential learning* and *trial and error* as information on their workings is limited to their limited tutorial guides. Parserr was learned by following guides on the website, but also by contacting their support line for advice.

A case study was primarily performed during the preliminary, but also continued into the master's thesis. This was however to a lesser extent.

6.2 Timetable

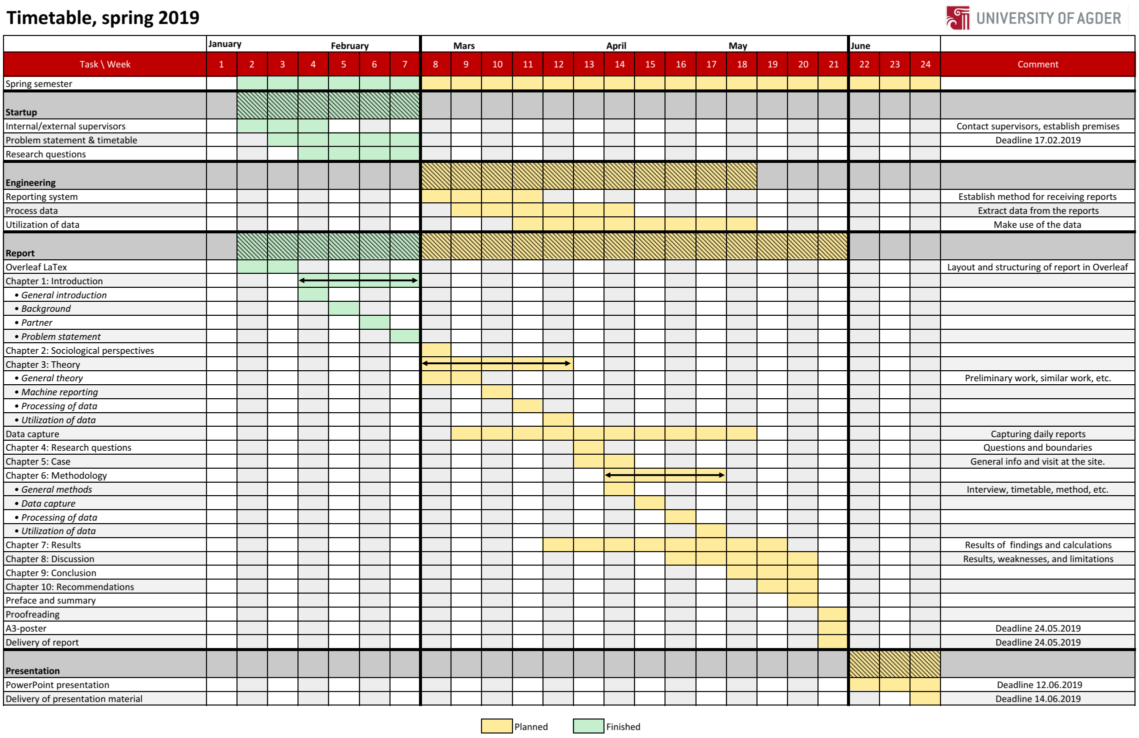


Figure 6.1: Timetable for the semester. Full scale version can be found in appendix C [28].

Figure C represents the timetable that was created at the start of the semester (Appendix C). It was created as one of the first steps for carrying out the master thesis. It maps activities and deliveries by weekly starting and finishing dates. The durations were an estimated effort at giving each task a sensible amount of time. The tasks were ordered by dependencies between the tasks. This ensured a certain progress and helped move the project forward.

6.3 Dealing with supervisor and contact persons

Communication between student and supervisor was done multiple ways. At the start of the semester it was established that there would be weekly meetings on Tuesdays at 10:00 with the supervisor. This was just formal in a sense as to proactively assure that both had the time available if needed each week. Meetings could be called off or confirmed at short notice for both since the time was already arranged. These meetings were performed as semi-structured interviews. Each meeting would have a set of prepared questions to be answered by the supervisor, as well improvising new questions that would come to mind during the conversation.
Other ways of communication were in the form of structured interviews by e-mail, which occurred sporadically, and by cellphone text messages in rare cases.

Contact persons in Skanska were mainly consulted through semi-structured interviews by video meetings in *appear.in*. These meetings would be arranged when needed, and they were planned some time in advance to assure everyone was available. These meetings would be spent by first updating the contact persons on the progress of the thesis, and

then continue with questions both ways in semi-structured interviews.
Structured interviews by e-mail were also prevalent. These were done sporadically if consultation was needed shortly. Depending on severity and as a rule of thumb it was done when a suitable amount of questions could be asked, to avoid burdening the contact persons.
Important notes and thoughts from meetings were written down in reports after each meeting. These can be found in appendix A.

6.4 Telematics reporting

This section explains parts of the results. It gives a brief explanation of the first part of the automated data collection method that has been developed. It will be put into context in chapter 7.

Weekly reports were set up from CareTrack and VisionLink. Each column in these reports represent an parameter, and each row represent the weekly values of a heavy equipment. The following procedure was performed during week 1 to 17, and the reports that resulted from this can be found in appendix F.

6.4.1 CareTrack

In CareTrack, equipment were selected based on their geographical location at the site. The chosen equipment was then saved to a group to easily be selected again at a later time. A weekly e-mail subscription was set up from the *Machine utilization* module for the group of selected equipment at the site. It is a sub-module to the Operation Reports module. The file format of the report was set to be an Excel file.

6.4.2 VisionLink

Relevant equipment in VisionLink was determined and selected by their geographical relevance to the site. A report subscriptions from the Unified Fleet and Unified Productivity modules were set up. The reporting interval was configured to be weekly, and the file format to be CSV.

6.5 E-mail processing

This section explains parts of the results. It gives a brief explanation of the second part of the automated data collection method that has been developed. It will be put into context in chapter 7.

Parserr was configured to extract the web address provided by incoming VisionLink e-mails. The web address given is direct to the downloading of each weekly report. After the web address had been successfully extracted it was then forwarded to Microsoft Flow.

Flow was configured to react on incoming e-mails from CareTrack, and data passed from Parserr. There were two rules set up in Flow:

6.5.1 CareTrack setup

This rule applies to e-mails that contain an attachment and are sent from CareTrack. Flow saves the attachment to a selected folder in SharePoint. When reports are received in my mailbox, Flow is configured to only react if the incoming mail is from an address with CareTrack in the name. If the e-mail has an attachment, Flow will proceed to the then extracts that attachment and renames the file name to *CareTrack_X*. The *X* represents a function for calculating the previous week number. It is then saved to a dedicated folder for CareTrack reports in SharePoint.

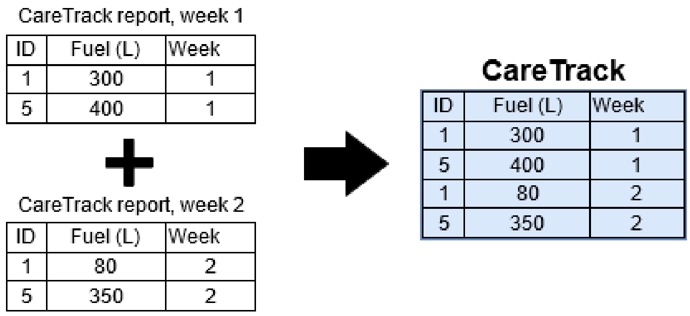
6.5.2 VisionLink setup

The web address forwarded by Parserr is opened, and then the report file is downloaded to a dedicated VisionLink folder in SharePoint. The reason for using Parserr with VisionLink is that the reports are not in the e-mail themselves. The e-mail contains a button you have to click to download the report. The button triggers a the opening of an URL address when clicked, that redirects to the file you want downloaded. By sending the e-mail to Parserr, the HTML code that the e-mail contains is written down. A filter is then applied that filters out the URL from the rest of the HTML. This URL is then sent to Flow, and then Flow downloads the file. Each file is given a new name of *VisionLink_X*, where *X* represents a function that gives the previous week number. The file is finally saved to a dedicated VisionLink folder on SharePoint.

6.6 Data analytics with Power BI

This section explains parts of the results. It gives a brief explanation of the third and fourth part of the automated data collection method that has been developed. It will be put into context in chapter 7.

6.6.1 Working with the data tables



CareTrack report, week 1

ID	Fuel (L)	Week
1	300	1
5	400	1

CareTrack report, week 2

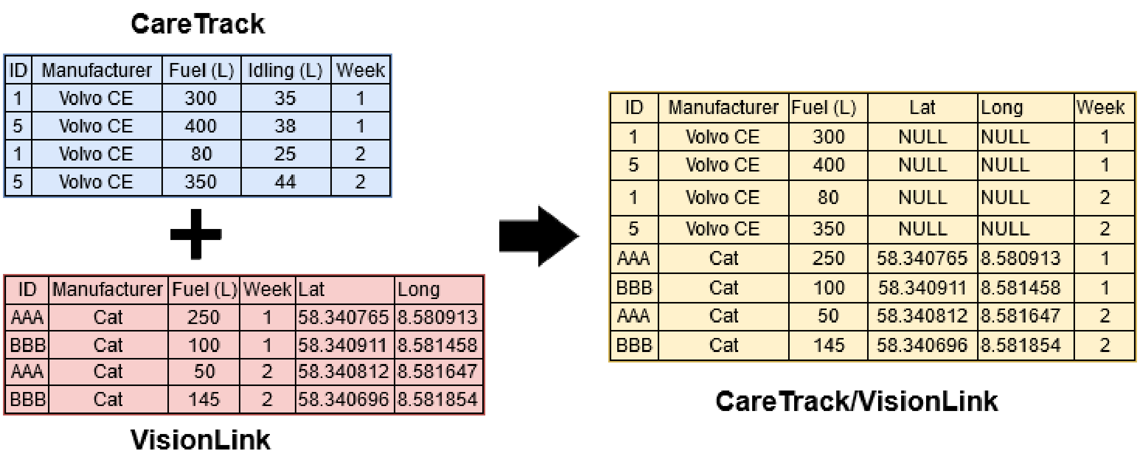
ID	Fuel (L)	Week
1	80	2
5	350	2

CareTrack

ID	Fuel (L)	Week
1	300	1
5	400	1
1	80	2
5	350	2

Figure 6.2: Simplified illustration of how the tables have been formated and added on top of each other through appending [28].

To associate similar manufacturer parameters, they had to be in the same table. In Power BI you start off by defining a source of data to work with. One source containing CareTrack reports and one containing VisionLink reports. These sources are queried individually from SharePoint. A template is created for both CareTrack and VisionLink data tables respectively. The templates defines which columns and rows that are to be used from each table. For CareTrack this meant removing the two top rows as they were headliner text, and the bottom row as it gave the totals of each column. Additional columns for manufacturer, equipment model, and week number were created by splitting existing composite parameters. While VisionLink uses the comma as a decimal separator, CareTrack uses a period. They had to be formated in the same way for Power BI to work with them. To work around this, each column from VisionLink was formated to be of German format while columns from CareTrack were formated to be British. Each report file is then formated according to the assigned template, and are appended on top of each other (Figure 6.2). Since each equipment identification number (ID) is only registered once per week number, the new large table will have rows of unique combinations of equipment ID and week number.



CareTrack

ID	Manufacturer	Fuel (L)	Idling (L)	Week
1	Volvo CE	300	35	1
5	Volvo CE	400	38	1
1	Volvo CE	80	25	2
5	Volvo CE	350	44	2

VisionLink

ID	Manufacturer	Fuel (L)	Week	Lat	Long
AAA	Cat	250	1	58.340765	8.580913
BBB	Cat	100	1	58.340911	8.581458
AAA	Cat	50	2	58.340812	8.581647
BBB	Cat	145	2	58.340696	8.581854

CareTrack/VisionLink

ID	Manufacturer	Fuel (L)	Lat	Long	Week
1	Volvo CE	300	NULL	NULL	1
5	Volvo CE	400	NULL	NULL	1
1	Volvo CE	80	NULL	NULL	2
5	Volvo CE	350	NULL	NULL	2
AAA	Cat	250	58.340765	8.580913	1
BBB	Cat	100	58.340911	8.581458	1
AAA	Cat	50	58.340812	8.581647	2
BBB	Cat	145	58.340696	8.581854	2

Figure 6.3: An example of appending different manufacturer reports [28].

The columns are then renamed appropriately for shared parameters to coincide with each other. All the CareTrack and VisionLink reports were then appended on top of each other (Figure 6.3). Columns that are equally named are aligned, while columns that differ are given NULL values if such parameter is not recorded for said vehicle ID. Some columns were removed as they are not used. This because of applying a Big Data philosophy for more efficient queries to the data source.

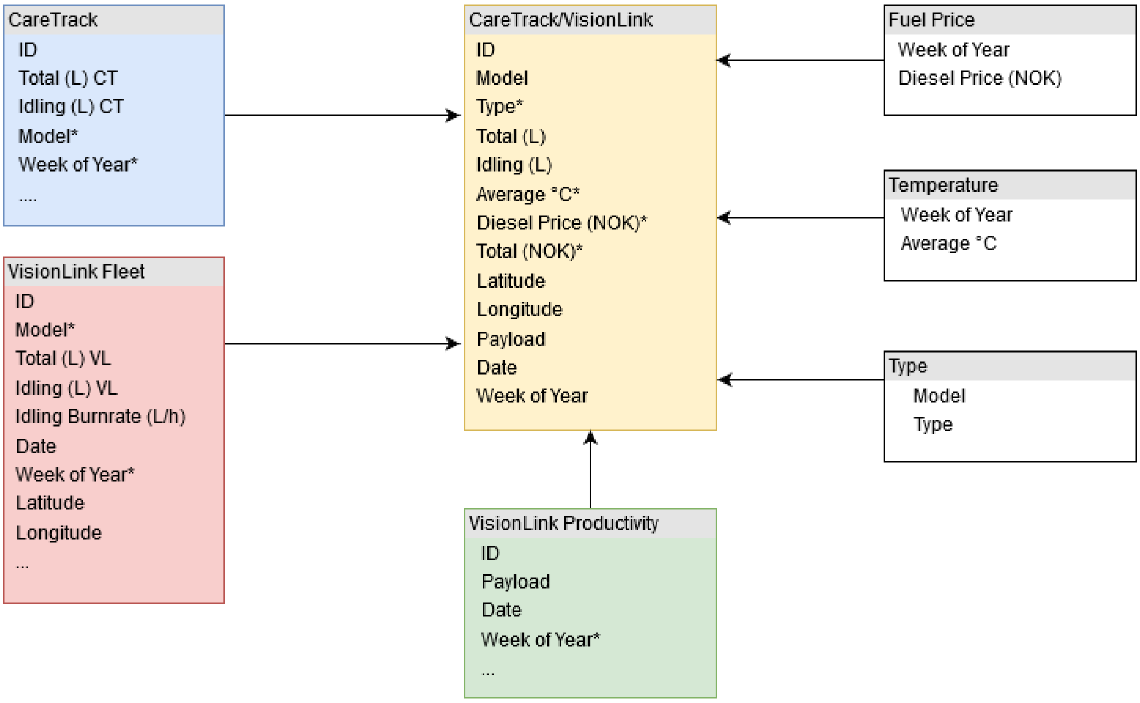


Figure 6.4: Overview of the source of each parameter that went into the main table (yellow) [28].

New tables were created to give additional relevant parameters to each heavy equipment. These were the average weekly diesel price, average weekly temperature, and equipment type. They were merged onto the main table through association with a common value in the two tables. For example, each weekly temperature was assigned through the *Week of Year* parameter. Another example of this is that the VisionLink Productivity reports do not come with the location of the equipment. By performing a merge with regard to the equipment identification number and week number, Power BI assigns the payload to the appropriate row entry. Figure 6.4 demonstrates how some of the parameters were merged into a greater common table. Every row in the figure represents a parameter in that table. An asterisk at end of a parameter indicates that it has been generated additionally to that table, as some parameter columns were calculated based on others. An example of this is that *Idling hours* is not reported by CareTrack. Instead it was calculated by multiplying the existing *Idling (%)* with *Machine hours* with each other. Since what the CareTrack parameters represented was unclear at times, appendix G was consulted to learn their true meaning.
Every new report that appears in the defined data sources will be run through each of the steps above. This is because Power BI records a recipe of each step performed by the user.

6.6.2 Data visualization

Power BI Desktop was used to generate graphical visualizations of the equipment data. There were applied different aggregate functions to the parameters in order to achieve different summarized values for all or parts of the equipment data. Each equipment ID is only registered once for each week number, so each row of data is unique. This is how Power BI was able to sort and assign parameters. Parameters that were empty were marked with NULL values, and would make that row entry ignored when aggregate functions were applied to the data set.
Filters could be applied to each parameter. By using the filter functionality I could pick one or multiple entries based on all the different values registered for that parameter. An example would be to filter based on equipment type.

6.6.3 Data sharing

The report and data set created in Power BI Desktop was uploaded to Power BI Pro. CareTrack sends its reports at 02:00 on Tuesday mornings, while VisionLink sends them at 12:00 noon on Mondays. Because of this the interactive Power BI report was scheduled to be refreshed weekly at 04:00 Tuesday morning. It would then query the latest reports from SharePoint into Power BI for data processing, before new statistics were generated.

6.7 Data authenticity and testing

Each weekly report was evaluated to assure some level of authenticity.

6.7.1 Reliability

The scheduled telematics reports were monitored closely for consistency in the reporting. A manual control of the contents of each report has also been done to ensure the consistent reporting from equipment. Appropriate adjustments were then made when anomalies occurred.

6.7.2 Validity

Data values were observed to ensure that there were no obvious mistakes in the numbers. This was done by familiarizing with the numbers and seeing if there occurred clear anomalies in the data.

6.7.3 Testing

The telematics systems were tested at different report configurations. The most rapid interval setting for reporting from both CareTrack and VisionLink is daily. Because of this, dummy files were created and sent from personal e-mail to Flow and Parserr to test the outcome at a higher rate.

7 Results

This chapter will present the results of the research questions (Chapter 4).

7.1 Automated collection of equipment data

A *proof of concept* that automatically gathers and presents data at the start of each week was achieved with the following setup. See appendix F for a more in depth manual to how the setup was achieved.

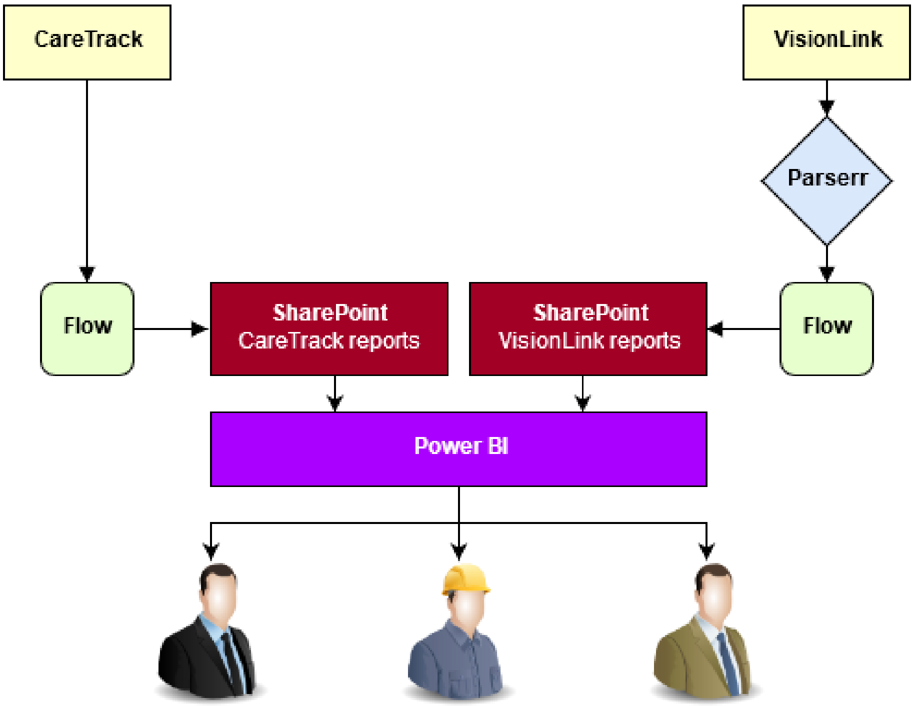


Figure 7.1: Illustration of the automated telematics method [28].

The automated solution for reporting the heavy equipment data can be seen in figure 7.1. The resulting method is simple to set up and implement. It has a low cost and relies heavily on existing capabilities. It enables collaborative effort for mixed-fleet telematics. The collaborative effort can be both across the different equipment manufacturer systems, but also between contractors. The method can be divided into the following four steps.

7.1.1 Step 1: Telematics reports

The telematics systems at the site are configured. Heavy equipment are selected based on their geographical location at the site. This is preferably done by defining an area for the site through geo-fences. Each system is then set up for weekly reporting of selected parameters related to utilization and productivity. The reports are set to be sent to an e-mail address of choice.

7.1.2 Step 2: Handling of e-mail reports

All incoming e-mail reports are processed. Flow and Parserr is configured to extract all e-mail attachments from the reports. Each attachment is named after the previous week number. The report file is then sent to a dedicated SharePoint folder based on which telematics system it came from.

7.1.3 Step 3: Data treatment

A Power BI Desktop report is created. It is configured to query the SharePoint folders as source of data. A template is designed for each different telematics report. Every report is run through their respective template and appended with the rest into a single data table. The data is then visualized through the graphical capabilities of Power BI.

7.1.4 Step 4: Data analysis and sharing

The Power BI Desktop report is uploaded to Power BI Pro. Here the report is configured to update from its data set at a fixed time each week. At what time depends on when the last report is received. In this environment the reports are analyzed and shared as a collaborative effort. The reports can be shared to members inside of the organization, but also among outside to the other contractors. New interactive visuals can be created in collaboration based on the data set that comes with the report. The data set is scheduled to refresh from its source once a week, right after each weekly telematics report has been received.

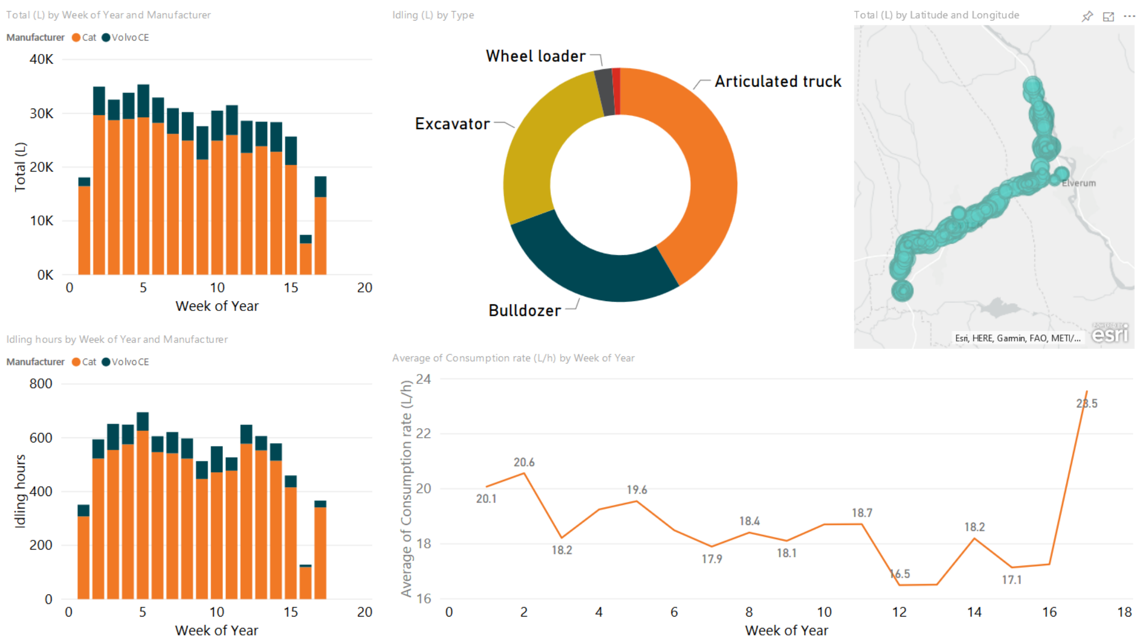


Figure 7.2: An example of an interactive report made in Power BI [28].

7.2 Results from Rv. 3 /rv. 25 Løten–Elverum

This chapter will look at ways of using the data that was collected from the case. The time period is limited to look at week 1 to 17, in 2019. This includes data from the Monday 31.12.2018, as it was counted in the weekly telematics reports. The final data table had 499 entries of data, where one row entry represents the weekly data from one machine.

N.B.: I want to give a reminder that the results are be taken as a proof of concept, nothing more. They do not give a complete picture of the situation at the case, as they only represent a part of Skanska's equipment at the case.

7.2.1 Weekly fuel use

Table 7.1: Total and weekly average fuel use at the case

	Total fuel (L)	Weekly average (L)	Weekly average per unit (L)
CareTrack	80 697,10	4 746,89	815,12
VisionLink	394 635,70	23 213,86	1 030,38
Sum	**475 332,80**	27 960,75	**986,17**

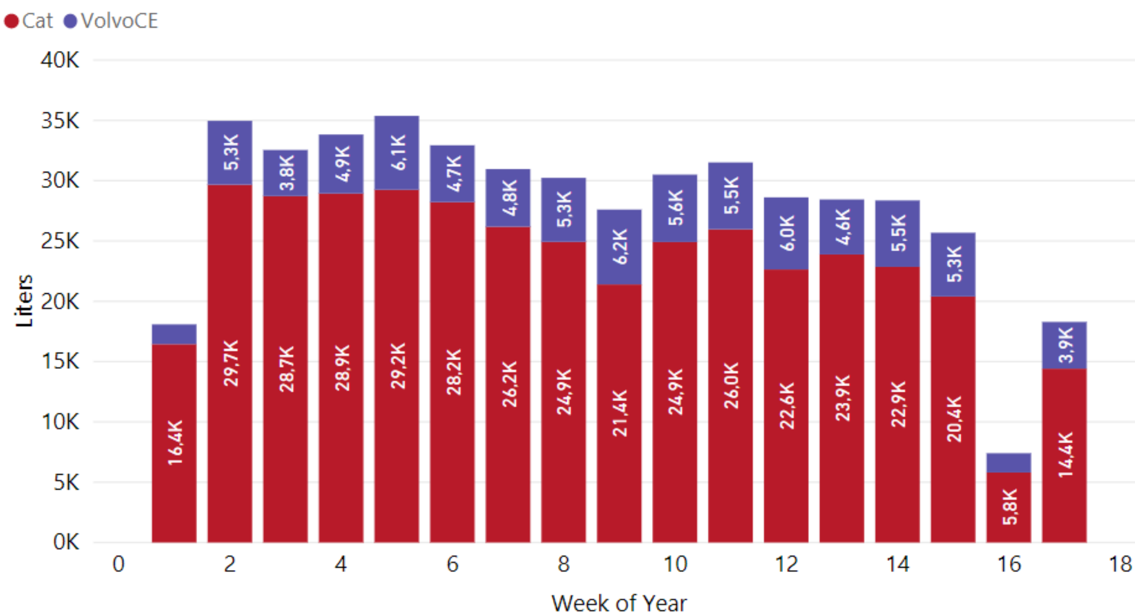


Figure 7.3: Total fuel consumed at the case [28].

The ability to tack fuel consumption can be used to better predict the actual fuel needed at a case (Figure 7.3). It is an effective way to optimize a project by providing more accurate predictions of fuel consumption trends. This will lead to better decision making in the process of buying fuel. The current situation at the case is that fuel is not bought at the fixed price. With better predictions, more efficient ways of buying fuel can be adopted. Dividing the fuel into averages (Table 7.1) is a way to help when scaling the project and adding new heavy equipment.

7.2.2 Idling

Table 7.2: Total and weekly average idling hours use at the case

	Total idling (h)	Weekly average (h)	Weekly average per unit (h)
CareTrack	1 047,41	61,61	12,77
VisionLink	8 114,40	477,32	21,24
Sum	**9 161,81**	538,93	**19,75**

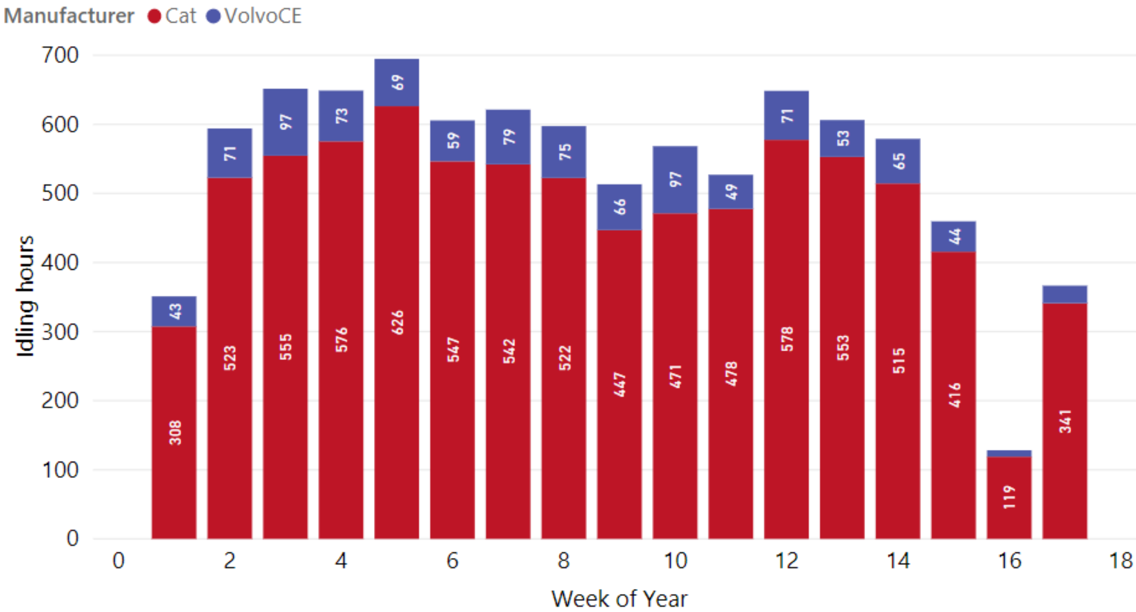


Figure 7.4: Weekly distribution of total idling hours [28].

Idling is seen as one the key ways of optimization through the use of telematics. Figure 7.4 and table 7.2 give the amount of hours spent idling at the case. Idling is a heated topic in the industry because it is essentially fuel going to waste. Monitoring the average amounts of idling for equipment could raise questions when some machines produce a higher amount of idling than the average would suggest (Figure 7.5). A high amount of idling would suggest operator issues that could be reduced through training of proper equipment use. Another issue that could be uncovered is the inefficient application of equipment. For example, too many articulated trucks being assigned for transportation of mass from the same loader, which results in a lot of waiting.

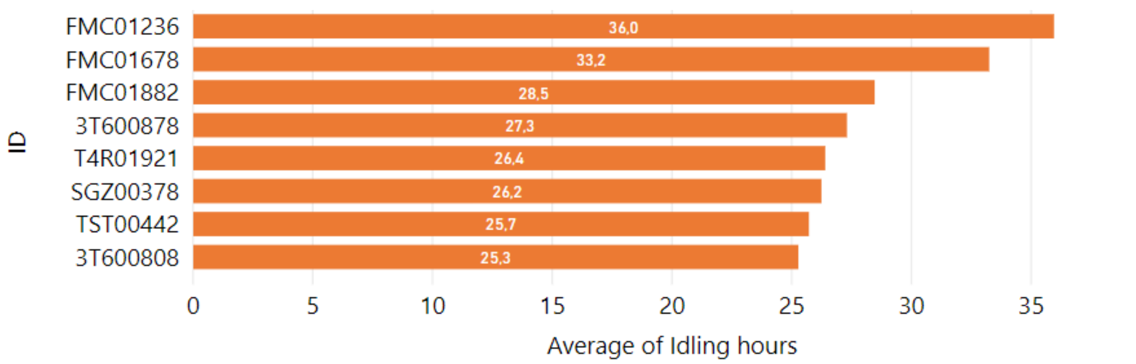


Figure 7.5: The total amount of idling for some heavy equipment at the case [28].

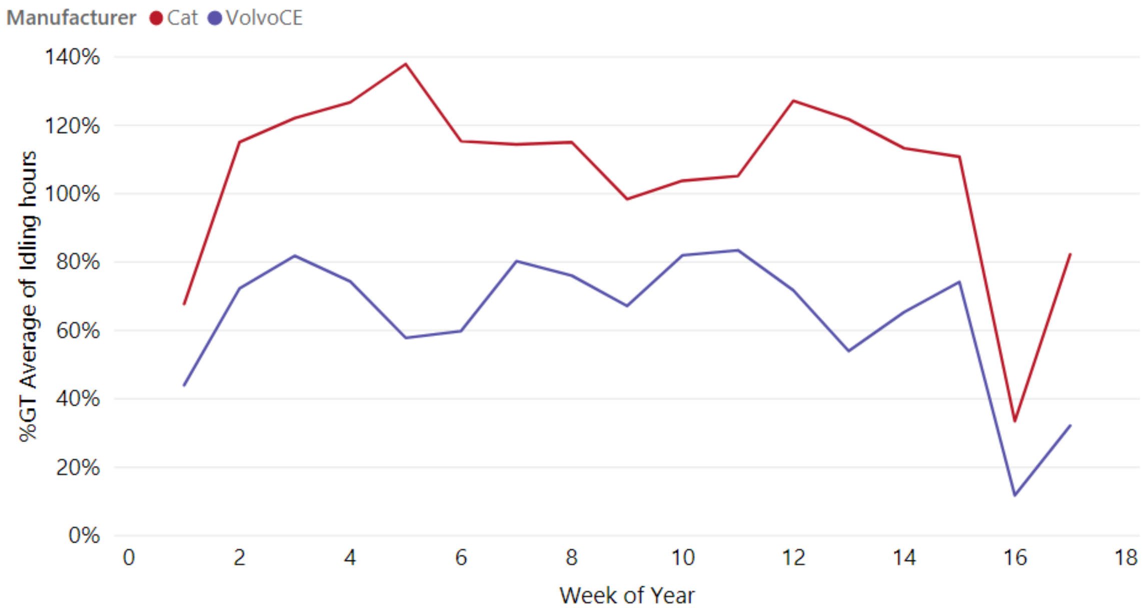


Figure 7.6: The average amount of idling hours for Cat and Volvo CE equipment, as a percent of the grand total average [28].

Comparing the averages between manufacturers can provide insight into operator issues with equipment. As figure 7.6 shows there is a clear difference in how much idling is registered by each system. Such data can provide insight into operator issues with the different criteria between equipment brands.

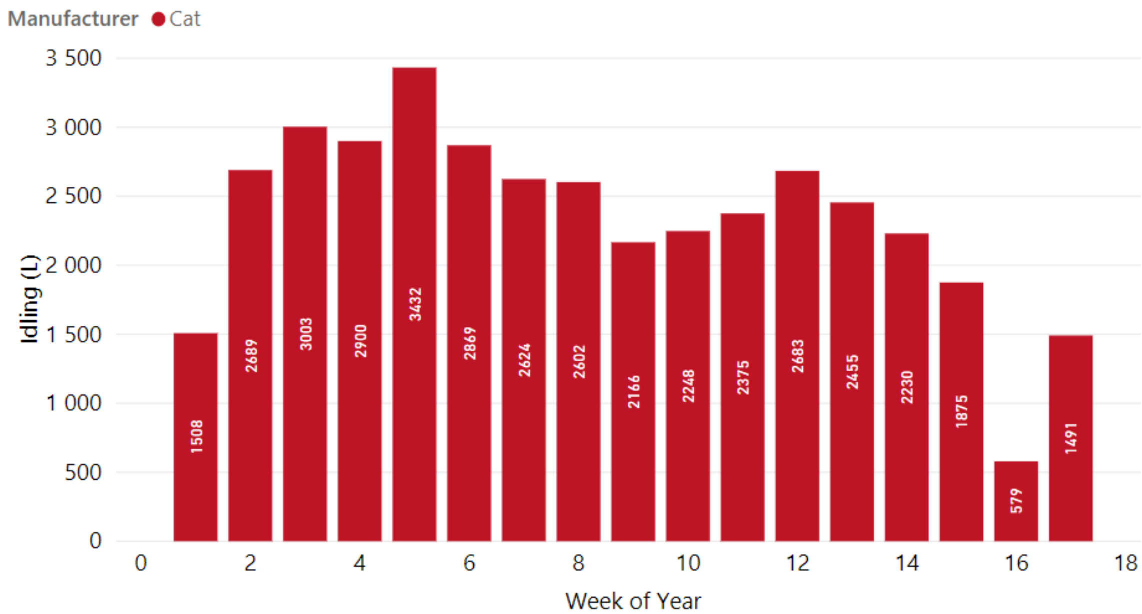


Figure 7.7: The weekly total fuel spent on idling for VisionLink equipment [28].

The parameter of liters spent on idling (Figure 7.7) can unveil how much is actually spent on idling. Fuel cost estimates can be made directly based on this data.

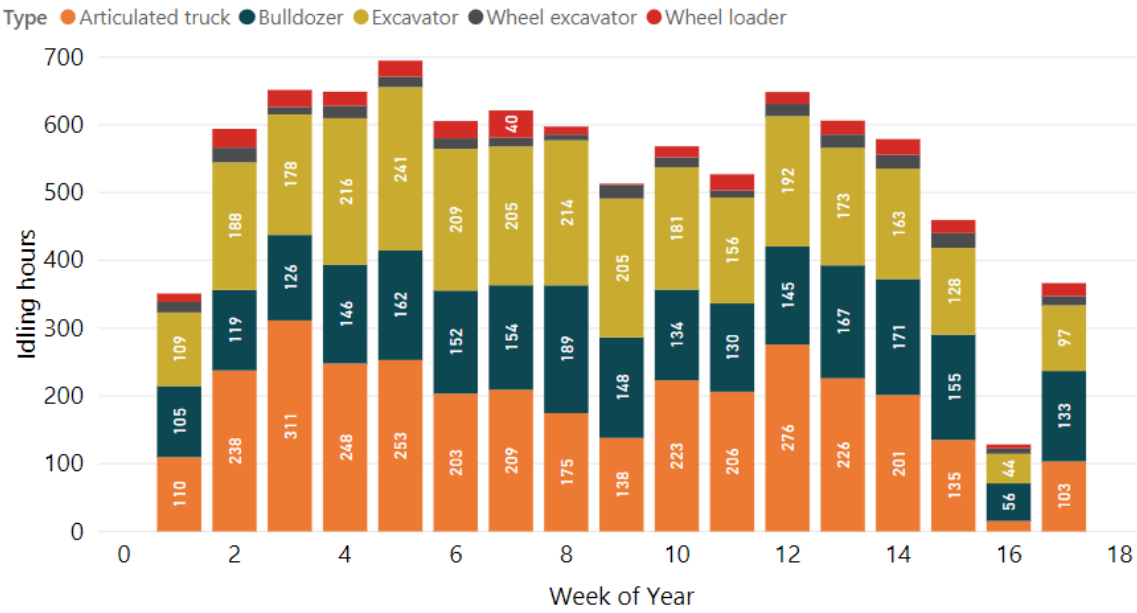


Figure 7.8: Average amount of weekly idling for each equipment type, as a fraction of the weekly total [28].

Sorting equipment by their types is a good way to measure efficiency. Figure 7.8 shows that the biggest contributors to idling at the project are articulated trucks and excavators. This is to be expected, as they are the most abundant equipment types at the project. Figure 7.9 however, gives another picture of the situation. Here the bulldozers appear to idle the most on average, while articulated trucks actually idle lower than the average of the case. By using parameter values together, a different situation is unveiled. The two figures would suggest that the biggest savings on idling would be to work on reducing the idling from articulated haulers and excavators. It would also suggest that the equipment that suffer the most from operator issues are the bulldozers.

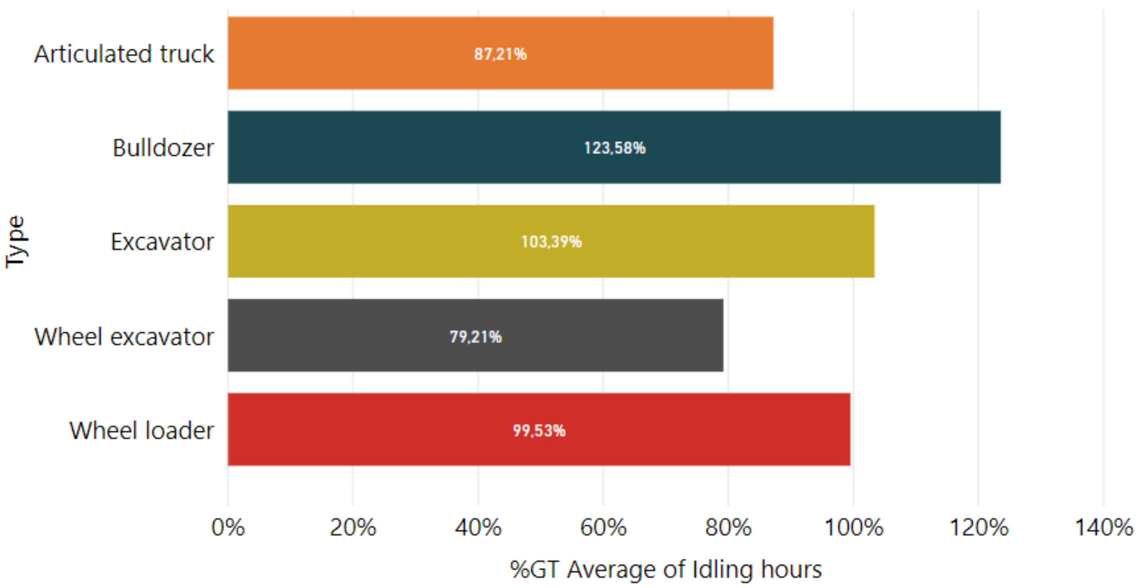


Figure 7.9: Average amount of weekly idling for each equipment type, compared as a percentage to the grand total average [28].

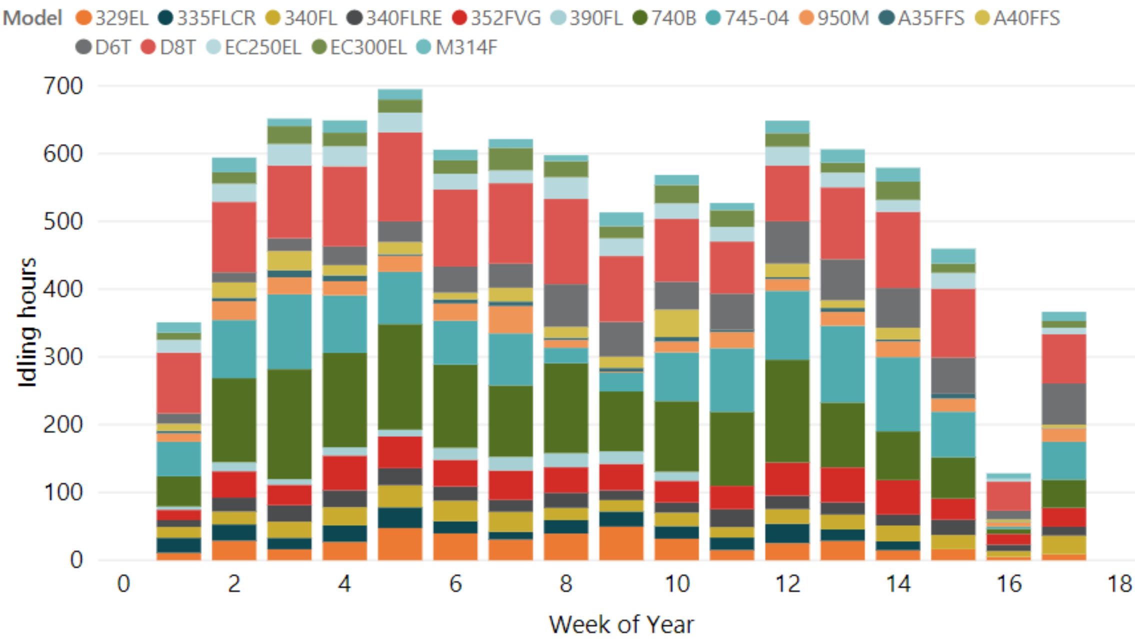


Figure 7.10: The distribution of fuel use per week by equipment model [28].

In figure 7.10 we see the distribution of weekly idling hours by equipment model. According to the figure, articulated truck 740B is the biggest contributor to idling on the project. Figure 7.11 points out that the equipment models with the highest average idling are the 329EL excavators and D8T bulldozers. These numbers can also be used for optimization through an understanding of trends for different equipment models. Comparing the performances of different models of the same equipment type can give insight into which models perform better. An example would be to compare the A35FFS articulated trucks from Volvo CE with the 740B from Cat.

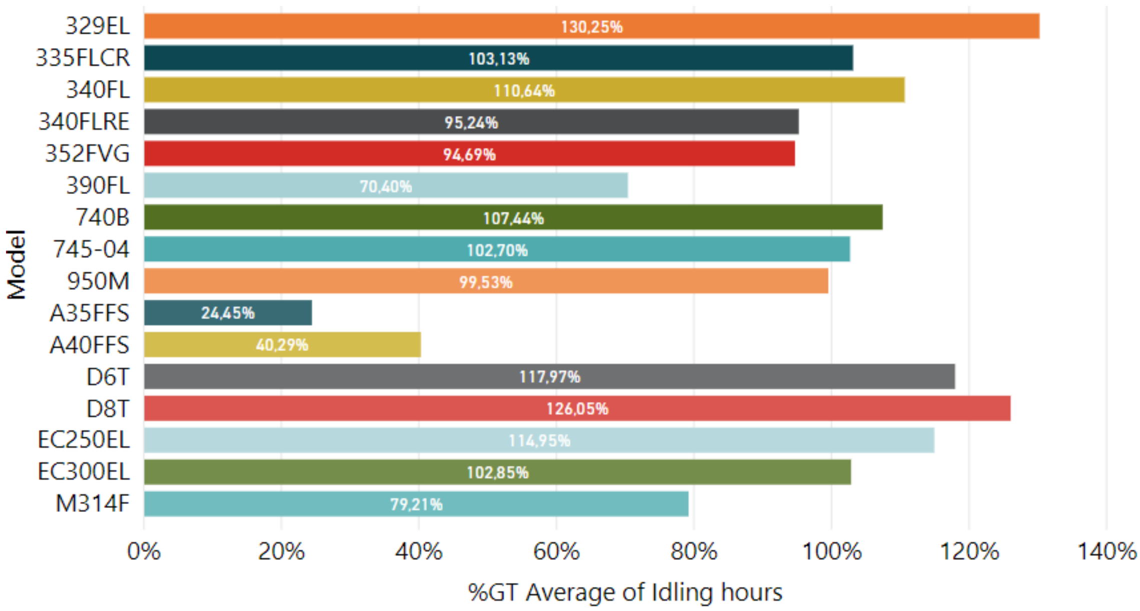


Figure 7.11: Average amount of idling per machine, as a percentage of the grand total average [28].

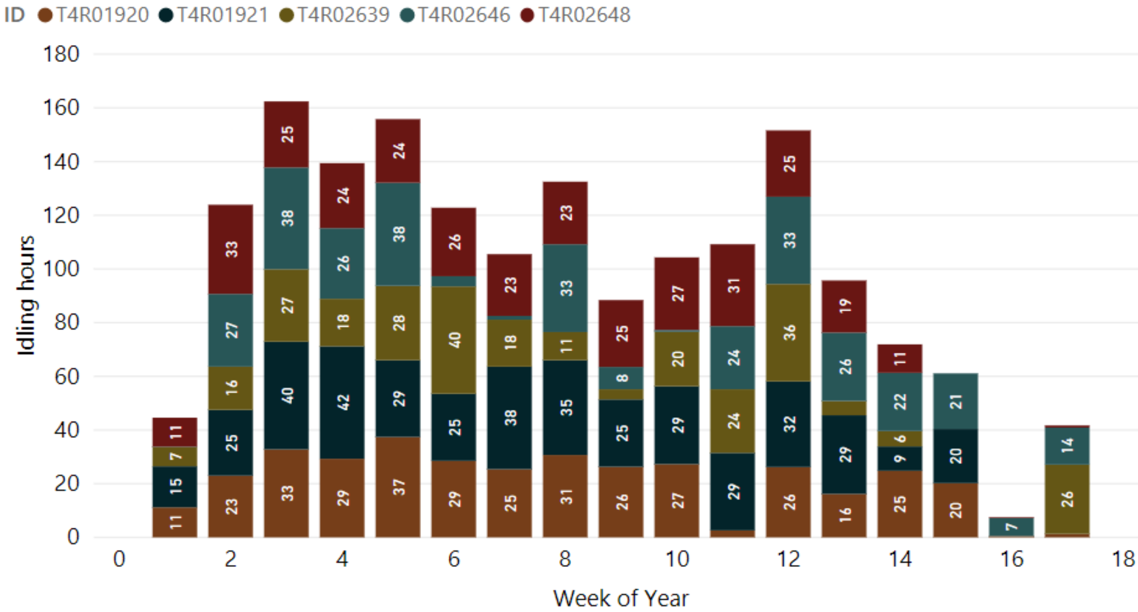


Figure 7.12: Weekly idling hours for 740B articulated haulers [28].

By dividing the models into each individual heavy equipment we get figure 7.12. This can be used to compare performances by operators of the same heavy equipment. It enables identification of operator issues through looking at their weekly habits.

7.2.3 Consumption rates

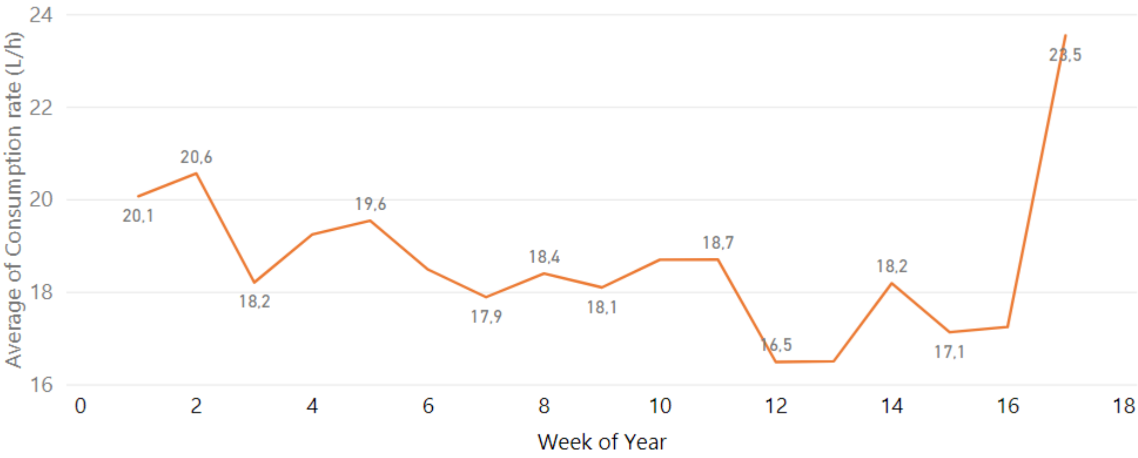


Figure 7.13: Average weekly consumption rate for all equipment at the case [28].

Consumption rates can give an indication as to the work rate of an equipment. By taking the weekly average consumption rate of all the equipment at the case, we get a sense of how active each week has been (Figure 7.13). Higher rates would suggest a lot of work, while lower rates would suggest inefficient planning.

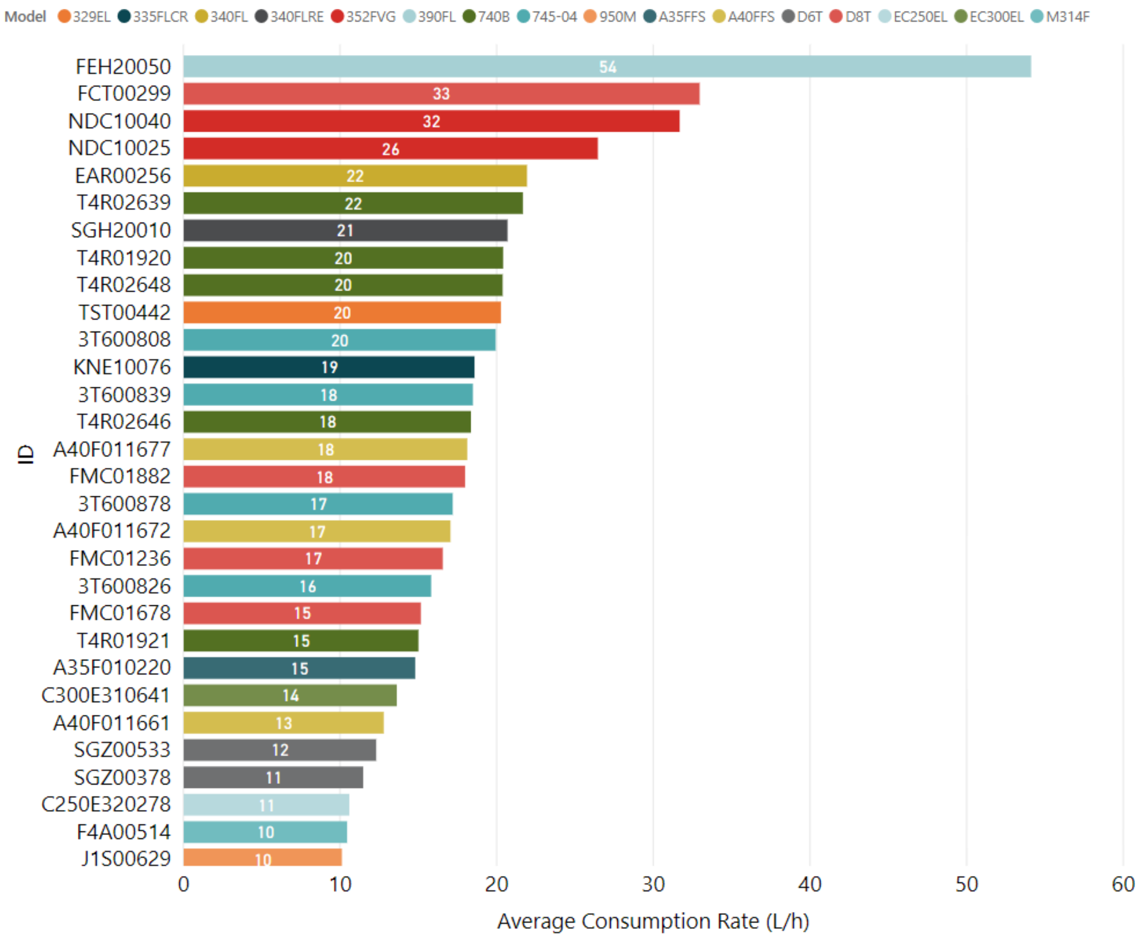


Figure 7.14: Average weekly consumption rate by each machine at the case [28].

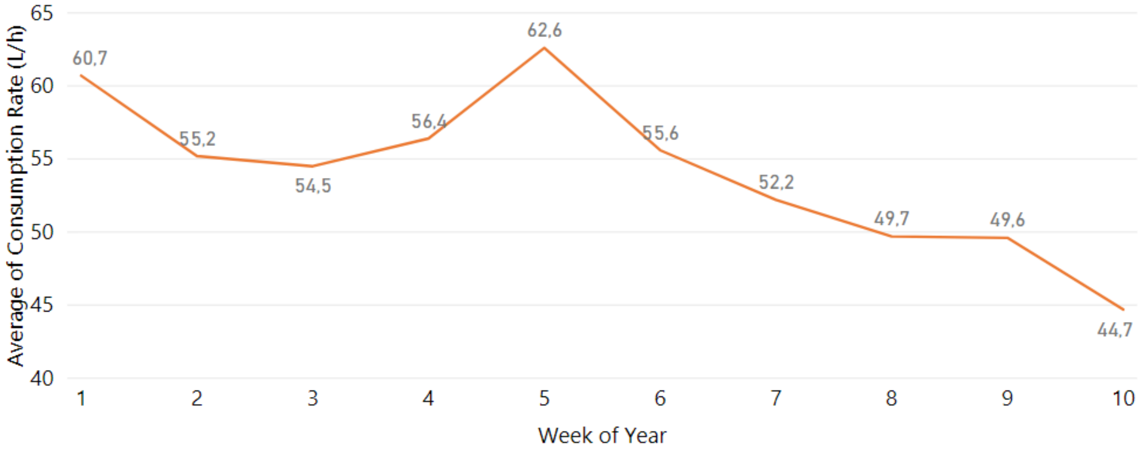


Figure 7.15: The weekly average consumption rate of an individual excavator [28].

Figure 7.14 compares the average weekly performance of individual equipment. Comparing equipment of the same models would be a good way to highlight operator issues or application problems. There is also the possibility to look at individual equipment history, like in figure 7.15. Graphs like this will highlight application problems clearly, for when equipment is not used to its potential.

7.2.4 Asset allocation

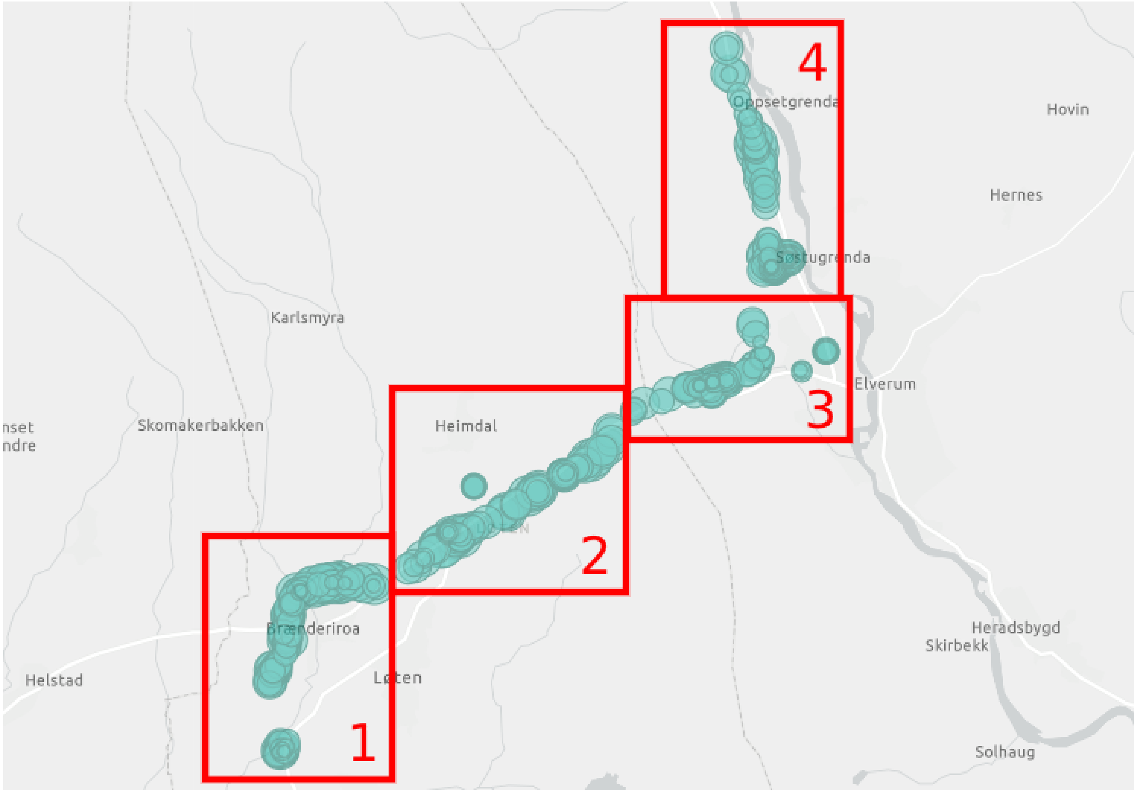


Figure 7.16: Fuel use distribution at the case [28].

Weekly parameter data can be attributed to a geographical locations. Each point in figure 7.16 shows weekly fuel use plotted to its geographical location at the site. The map has been divided into areas, with data values of each area given in table 7.3. Enabling fuel use to be geographically allocated has both optimization and environmental applications. Using the data can provide pollution patterns to the project, down to each week if necessary. Potential applications could be to map the local abundance of harmful emissions like CO, NO_X, HC, and SO_2.

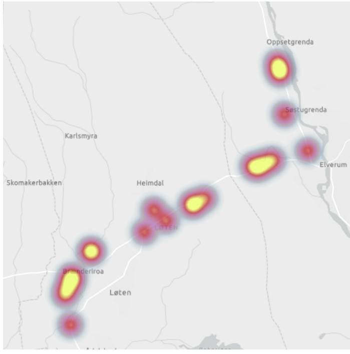
Table 7.3: Fuel used in each segment defined by figure 7.24.

Area	Fuel (L)	Average weekly idling hours	Average consumption rate (L/h)
1	119 946,20	24,72	19,97
2	104 960,40	19,21	21,41
3	67 604,40	22,96	18,50
4	102 052,70	19,86	19,33
Sum	**394 635,70**	**21,69**	**19,80**

As table 7.3 shows there can also be calculated an average amount of idling hours for each of these areas. This can be used for optimization when comparing different areas. One area having significantly higher amounts of idling hours would indicate problems with the application and planning involved in that area.

(a) Week 1 and 2

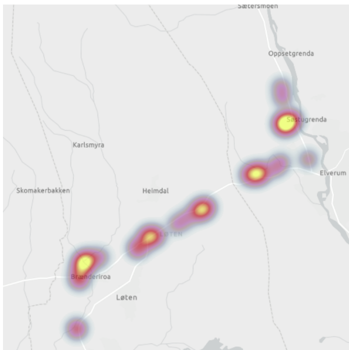
(b) Week 3 and 4



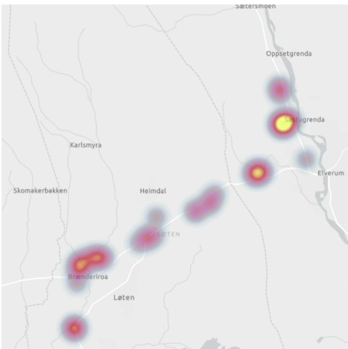
(c) Week 5

(d) Week 6 and 7

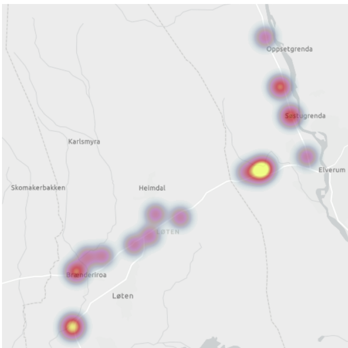
(e) Week 8



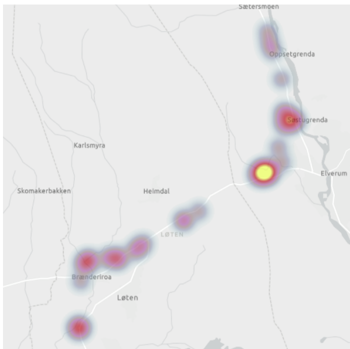
(f) Week 9 and 10



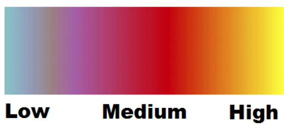
(g) Week 11 and 12



(h) Week 13



(i) Week 14 and 15



(j) Heat map legend

Figure 7.17: Heat map distribution showing the density of equipment [28]

Generating heat maps based on the equipment location can highlight the movement of activity and pollution at a site. Figure 7.17 shows the density of equipment for a geographical location over time, and was generated with ArcGIS. By monitoring the density of equipment in an area over time, a good view of where activity is occuring on the site can be achieved. From an environmental perspective, similar maps can be done for fuel use in an area. In that case, local pollution patterns over time can be generated.

7.2.5 Payload

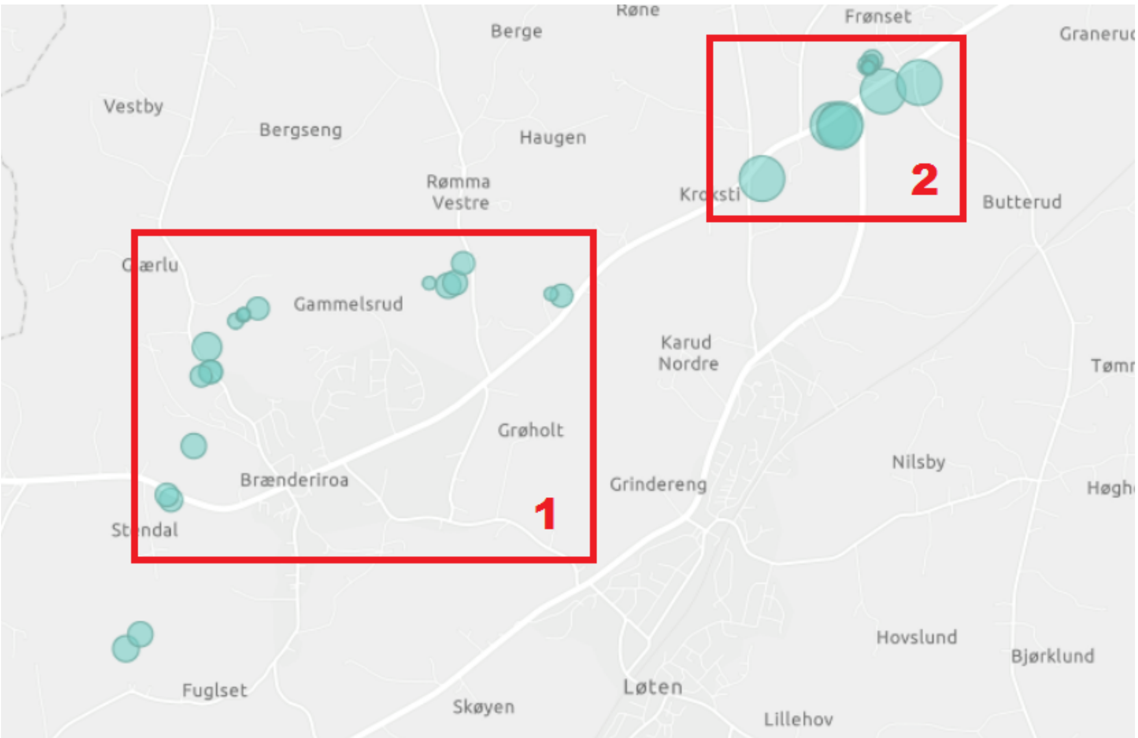


Figure 7.18: Payloads by location at the site [28].

Payloads can be coupled with the equipment location data. This has potential use in optimization by tracking how much mass has been excavated and moved from different locations. Figure 7.18 together with table 7.4 show the amount of mass lifted by excavators and wheel loaders. It also gives the amount of mass transported by the articulated trucks stationed in the respective area.
The amounts of mass per equipment cycle for each area is shown in table 7.5. This is another way of looking at how productive an area is.

Table 7.4: Payloads by area and equipment type. Areas are defined by figure 7.18.

Area	Articulated truck (kg)	Excavator (kg)	Wheel loader (kg)
1	133 287,00	0,00	0,00
2	0,00	1 278 227,00	10 080,00
Sum	**133 287,00**	**1 278 227,00**	**10 080,00**

Table 7.5: Cycles by area and equipment type. Areas are defined by figure 7.18.

Area	Average metric ton per cycle	Average cycle per hour
1	33,94	4,10
2	20,26	33,63
Sum	**27,10**	**18,87**

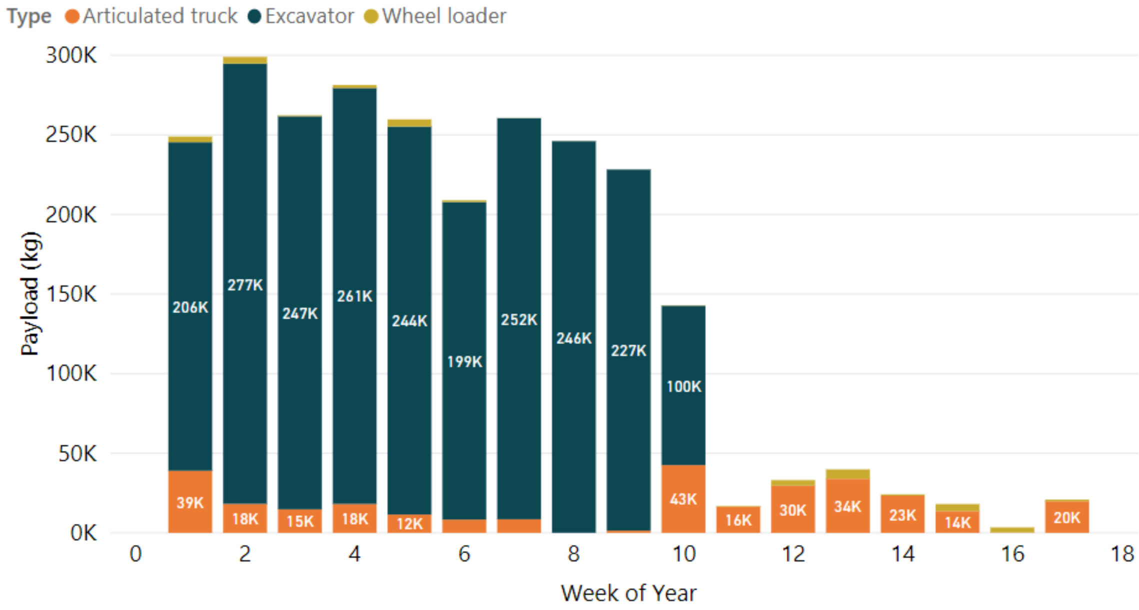


Figure 7.19: Weekly distribution of payloads by equipment type [28].

The weekly amounts of payload treated by different types of equipment can be seen in figure 7.19. It shows the total payload carried by the different types of equipment for each week. Closer inspection of equipment productivity, like that of the 390FL excavator in figure 7.20, can be used to monitor how productive the equipment is.

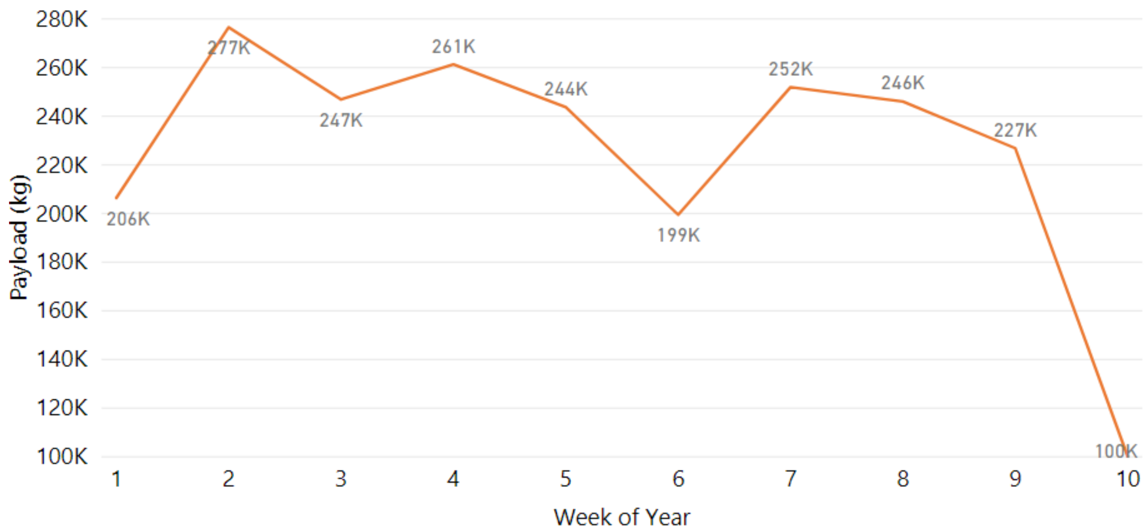
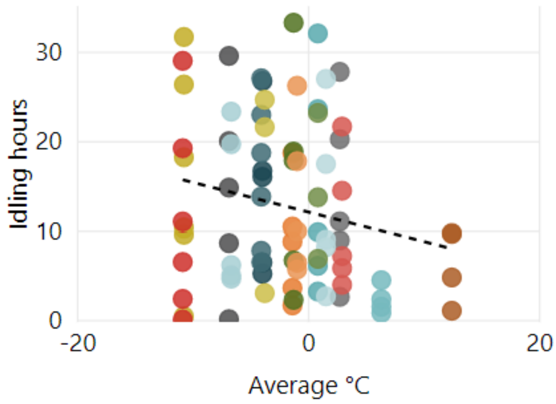
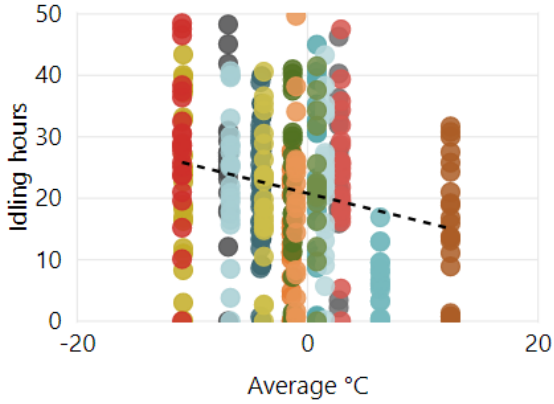


Figure 7.20: Weekly amount of payload lifted by 390FL [28].

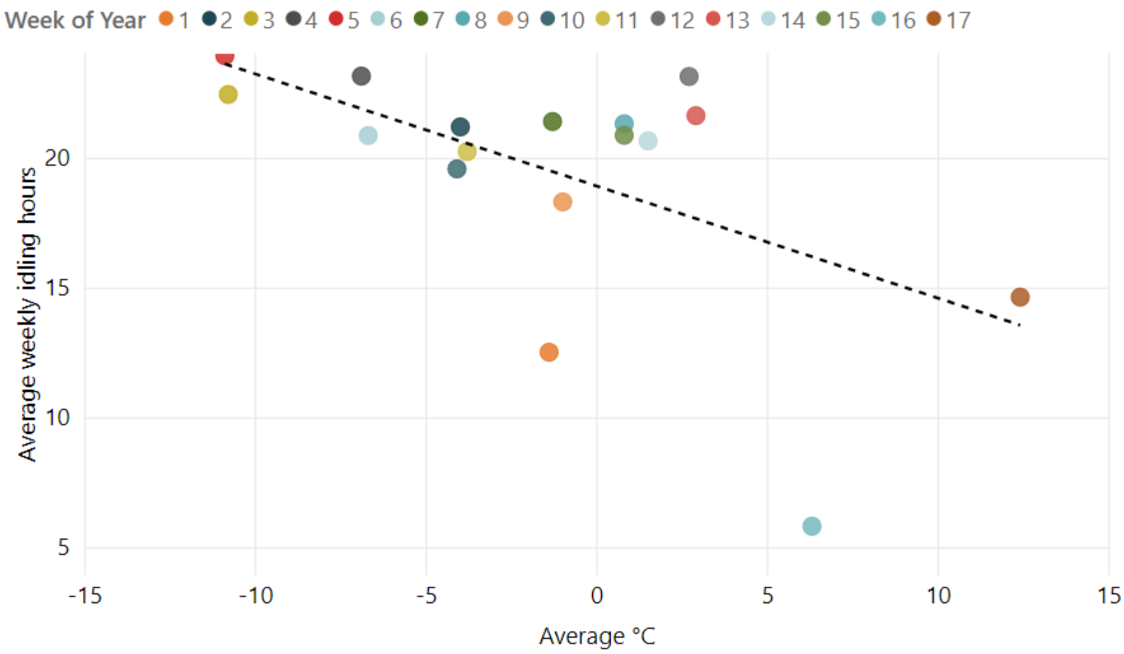
7.2.6 Regression analysis of idling temperature



(a) Data points from Volvo CE equipment



(b) Data points from Cat equipment



(c) Regression line for the weekly sum of idling from CareTrack and VisionLink

Figure 7.21: Regression lines for the scatter plot of average weekly idling hours, set against the average weekly temperature.

Performing regression analysis of data can expose connections between two parameters that do not appear to be related. Figure 7.21a and 7.21b shows the scatter plots for CareTrack and VisionLink, respectively. The weekly average idling hours between CareTrack and VisionLink is shown in figure 7.21c. A linear regression line has been generated from setting the average weekly idling at the case against the average temperature of that week. The figure indicates a correlation that can be acted upon to optimize a side of the case.

7.2.7 Forecasting

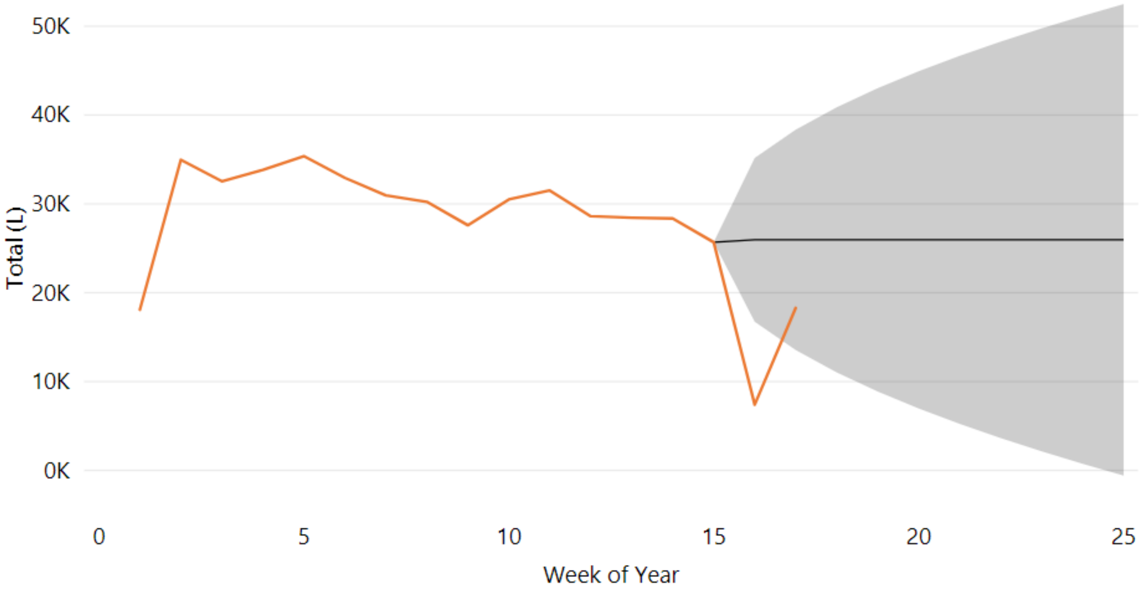


Figure 7.22: A forecast analysis of predicted fuel use for the coming weeks [28].

By having a history of data parameters from heavy equipment, better forecasting analysis can be produced. A forecast analysis of the weekly fuel projection can be seen in figure 7.22. It is based on previous fuel use of the previous weeks. In this figure, the analysis has been configured with a confidence interval of 95 percent. Week 15 and 16 have been disregarded because of the Easter holiday.

7.2.8 On-site assistance

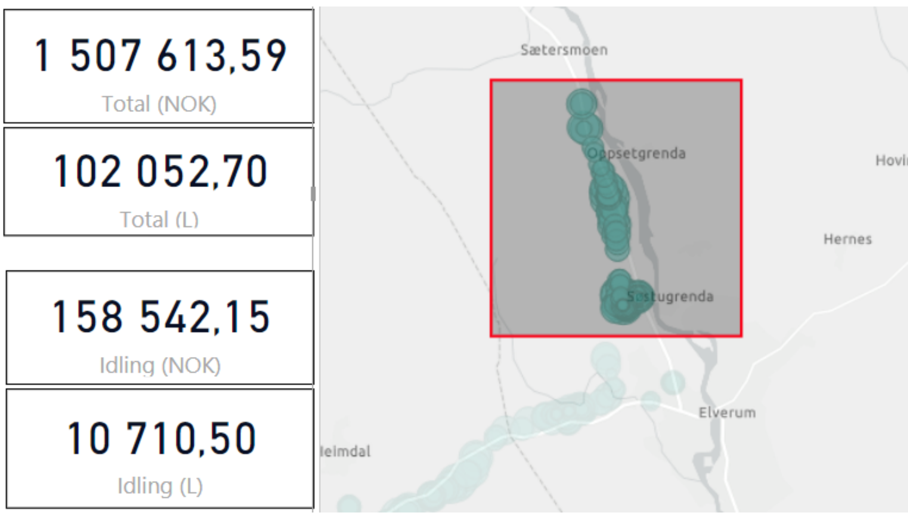


Figure 7.23: The costs involved with fuel consumption in an area [28].

The ability to provide the latest data about the heavy equipment performances at a case to operators on the site has potential benefits. Much like a BIM-kiosk, allowing the workers a visual relationship to their performance can encourage better use of the heavy equipment (Figure 7.23). Discussions on the general performance of the fleet can also be had at meetings, providing the data as a foundation for the assessment.

7.3 Future applications of equipment data

A concern from Skanska was the ability to stay competitive in future procurement processes. This section will look at how telematics data can be used in future procurement processes.

7.3.1 Documentation in public procurements

Tendering documents are applied to every public infrastructure projects in Norway through Anskaffelsesloven. The procurement process involves using life-cycle costs for factors that can be cost estimated. Some telematics data can be cost-estimated, and it is therefore possible to include telematics data in the procurement process.

7.3.2 Future projects

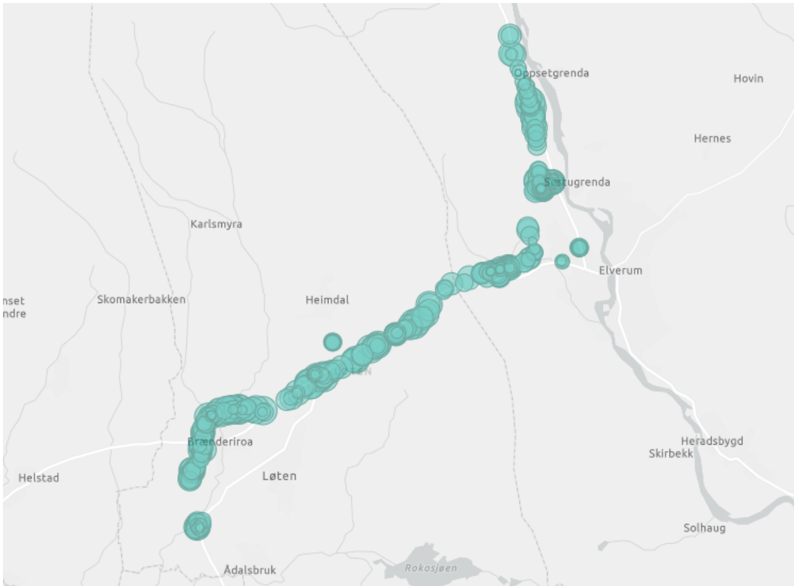


Figure 7.24: The location weekly reports from equipment at the case [28].

Telematics data can be used for more accurate bids and estimates for procurement of future projects. By recording actual historical data from the site, estimates can be more competitive for future tendering processes. Data from earlier projects can also be analyzed to provide better estimates.. Using a history of fuel and machine hours reports, the labor and equipment operating costs can be determined more accurately. In turn, these costs can be compared to earlier similar procurements processes for better determining the actual costs in bidding processes, and give better competitive bids.
Anskaffelsesloven has evolved to include environmental considerations as criteria in the tendering process. Environmental impacts can be included as life-cycle costs if they can be calculated. The telematics data can be used to provide this by applying actual fuel data. The data can also be allocated site activities through geographical location (Figure 7.24). This can then be used as a measure of how environmentally friendly it was performed.

As the BVP method is being adopted into public procurement deals, there is also a need for documentation to occur during the execution phase of a project. Telematics can be used to supply such data throughout the construction phase.

8 Discussion

Heavy equipment telematics have been around for years now. However, companies are slow at adopting and using the potentials that it brings. This thesis demonstrates a proof of concept for the automation of collecting mixed fleet telematics data. With optimization and environmental benefits, but also with current and future aspects in mind. The following chapter discusses the results (Chapter 7) in relation to the theory (Chapter 3).

8.1 More efficient data collection

Because of low utilization of telematics at the case, there was an interest in finding a way to collect the data from heavy equipment more efficiently. The mixed equipment fleets are problematic because they each have their own set of manufacturer telematics system. With each contractor only having access to their own equipment data, it is inconvenient to collect telematics data. It also gives an incomplete picture of site activity, since only parts of it are recorded.

8.1.1 Data automation

To tackle the inconvenient use of existing telematics, I asked whether there could be a way of automating the collection of telematics data. Figure 7.1 shows a method for how collection of data can be fully automated. Through this method there is no need for any worker interaction with the process of collecting and storing telematics data. Instead of reading through thousands of individual documents everything is gathered, processed and visualized without user interaction. This is convenient and will provide statistical history at weekly intervals throughout the project lifetime.

There was a choice made early on to limit the study to Cat and Volvo equipment owned by Skanska. It was important to have two different manufacturer systems, as the intention was to provide a proof of concept for a mixed fleet. Other manufacturers, like Hitachi, only had very few equipment at the case. Spending time learning the telematics system of Hitachi equipment would not be a good investment when there was only one excavator at the case. This lead to the exclusion of several equipment based on manufacturer, but also on the fact that some equipment was not fitted with telematics equipment for data to be received from them. This study is in no way a complete picture of the site activities at the case.
It is because of the ISO 15143-1 and ISO 15143-2 that the data parameters are formatted in a comparable way between the telematics systems. The cumulative values of parameters that are related to performances makes the solution scalable down to daily or up to monthly reports as well. Daily reports were considered and tested for some time, but it was never viable as CareTrack had issues with daily reporting. Every report received reported no activity from the heavy equipment. I contacted Volvo Maskin AS about the issue and they acknowledged that there is an issue with the daily reporting. It is caused by CareTrack reporting data from 00:01 to the reports being sent out at 02:00. As suspected there are no equipment activity at these hours. Feedback from interviews with Skanska made it clear that they were interested in weekly reports in the first place, so it made sense to change the approach to weekly reporting.

Choosing what equipment to track through their geographical location at the site is not a sufficient way to get data from the site. The equipment can be moved out of the project at any time, which would then result in data being reported from the outside of the project. This can probably be fixed by applying geo-fences, which CareTrack and VisionLink both support. The reports would then be set to report from equipment within the fence. This was however not thought of as an issue until it was discovered that two machines had left the site at the end of this study.

Using Flow for reporting the CareTrack reports was relatively easy to do. How to handle the VisionLink reports was however an issue that was worked on for some time. Fortunately, Parserr was discovered through literature reviews. It is not the best option as there is a limit to the amount of monthly e-mail one can receive. An investment into a higher capacity is still very little compared to the potential savings of utilizing the telematics systems.

Storing the individual weekly reports in SharePoint seems like a fair solution. It is an attempt at the tackling the looming issue of too many reports being generated from bigger infrastructure projects. Since there are limits as to how far back in time data can taken from the manufacturer systems, it is necessary to store the data as it otherwise will be removed one day. Infrastructure project are unlikely to generated extreme amounts of reports, but that will depend on how big the equipment fleet is and how much data is being reported. The amount of data could reach levels where it becomes inconvenient to load it, because of processing time. In terms of Big Data, one problem with storing the individual reports in SharePoint is that they all contain unused data. A solution to this would be to extract the necessary data from each report and dispose of the rest. This is is essentially what Power BI does each time it does weekly refresh of the data, and it could be further investigated.

Power BI was a learning process. A lot was learned about the software through experiential learning, trial and error, and observation by video tutorials on the internet. The use of queries to assemble pieces of data from each weekly report turned out to be quite an effective way to analyze the data. There was required some initial work to learn to configure the report templates in Power BI, but this can easily be learned and done quickly by a person. From experience there should be no problem adopting this method.
Another option to the resulting method would be to use the telematics system API. Accessing the data straight from the manufacturer database instead of accessing the telematics web interface as a middleman seemed to be the better option. Initial test were conducted with the CareTrack API. It was defined as a source directly into Power BI, and data was received. The API data supplies the equipment location of the Volvo CE equipment as a parameter. There is then the potential for this to be merged with the other CareTrack parameters to provide location to the data. Combining the data from e-mail reports and API would then be possible to give the Volvo CE equipment location data as well. It was however decided against using this approach because it would require additional programming knowledge to store the data.

Because of experimentation with report types and automation setup in the first half of the project, there were several weeks that were not recorded through the automation method. These reports were manually created at later dates by accessing the VisionLink and CareTrack web interfaces. The files were renamed and put with the rest of the reports in the SharePoint folder. It would have been interesting to do further back time. CareTrack would eventually limit the weekly reports at 13 months back in time, but it would have provided a better picture of the case. One of the figures that would have benefited the most from this would be the regression line from average temperature and idling hours.

8.1.2 A collaborative effort

A question that became prevalent because of the mixed equipment environment, was whether there could be a collaborative aspect to the collecting of data between the different equipment manufacturers. Given that the telematics systems of the major equipment manufacturers in Norway provide telematics in line with the ISO 15143 standard, there is common ground for mixed fleet data to be compared and used together. This assures that there is some common ground between the telematics parameters reported, and enable the juxtaposition of existing telematics capabilities.

The automation method has good scalability since it is using e-mail reports, and there is then no end to how many different reports can be received this way. E-mail reports could also be set up from the telematics systems of other contractors at a project for a more complete view of the site.
Using Office 365 as a platform for the data automation will potentially work well from a perspective of cooperation. The platform is both safe and reliable, and Microsoft offer several possibilities for businesses to use Office 365. The reports that are stored in SharePoint are available to those who have access, and Power BI generated reports can be shared effortlessly between contractors (Figure 7.2). As you only need one person with Power BI Desktop to create the reports, this can be done without much effort. Using Power BI Pro, other workers can interact with and create new visuals from the resulting data set without having to do any configurations themselves.
An interesting perspective would be if there could exist a group of workers specialized in handling all company telematics from different projects. Their job would be to allocate relevant statistics and analysis to different projects, and actions that can be taken to optimize the site. They would also cooperate with similar workers in other organizations to provide a complete picture of site trends.
The introduction of telematics API with ISO 15143-3 have also made third-party telematics providers like TrackUnit a viable option. Third party telematics appears to be a good option for gathering data from several different telematics systems in mixed fleets. Even though there are investments involved, these are companies that specialize in providing solutions for mixed fleets.

8.2 Useful telematics data

An interest from Skanska was to look at how existing telematics capabilities could assist their projects. This research was achieved through doing a literature study of what is considered valuable parameters in heavy equipment telematics, and referencing it to the available data at the case.

Tracking the weekly fuel use of the equipment fleet is central to the optimization of projects. Using the results related to fuel use we can read trends relating to how efficient a site is. From figure 7.3 we can read that there is a decreasing fuel consumption as the weeks go by. This is with the exception of week 1, 16, and 17 where there were transitions from holidays. If the values in table 7.1 were viewed without the context of figure 7.3 one would believe the weekly averages. But because of the holidays they are actually portrayed lowered than what they should be. This is a simple demonstration of how powerful simple visualizations can be. In figure 7.22 data about the weekly fuel use of the case has been used to generate a forecasting. Recording parameters over time gives a better opportunities for predictions and following decisions to be made.

Idling parameters appear to be powerful tools in optimizing an equipment fleet. MEF stated a daily idling percentage 30 to 50 percent, which is in accordance with 21,24 hours stated by table 7.2 for Cat equipment. This is considering the maximum of 40 hours of work per week by law in Norway. The 12,77 hours reported for equipment from Volvo CE is probably skewed because of its low amount and models of equipment at the case. It is also important to remember that there are some differences in operator techniques required for the heavy equipment to register idling. The skewed amount of heavy equipment between the systems is most likely the case with figure 7.6, which shows a significant disfavoring of Cat equipment. Figure 7.7 was only available to generate because there are currently no parameter reported by CareTrack that could give an accurate amount of liters spent on idling. It however shows that around 10 percent of the total fuel budget for Cat equipment is spent on idling, when compared to table 7.2. There are unfortunately no parameter for idling liters in CareTrack. There is a percentage of idling hours in CareTrack, but those are different parameters that should not be mixed with each other. Assigning parameter values to heavy equipment types and models does also appear to be an effective way of learning about site activity. Figure 7.8 shows the amount of idling hours per type being closely related to the idling total hours of each week. It suggests strong routines from the workers, as it otherwise would fluctuate more. Figure 7.10 in contrasts shows a bit more variation from week to week when looking at each model. At closer inspection of the 740B articulated trucks in figure 7.12, it would appear that you can trace when the shift of workers occur. It has been stated that they work 14 days on, followed by 14 days off. The variations appear to occur in pairs, which is especially true if you watch *T4R01921*. Calculating the average of grand total, like in figure 7.9) and figure 7.11, proves to be another insightful way to highlight trends that would otherwise be missed. But it is together with other diagrams they really shine.

If we compare the average weekly fuel consumption of 7.13 to the weekly fuel use in figure 7.3, we can interpret that week 1 had a slow start after the winter holidays. The high consumption rate does not reflect on the low amount of fuel used for that week. On the other hand, week 12 displays the lowest consumption rate of the period while having moderate fuel use. This would indicates that week 12 had low activity, which is supported by the fact that it shows a peak in idling compared to weeks around it. In figure 7.14 the high consumption rate of excavator FEH20050 is somewhat misleading to put into context. It is the only 90 metric ton excavator at the project, and from the numbers appears to have been put to good use. A deeper look at the excavator in figure 7.15 reveals that it had a decline in consumption rate from week five to week 10, which suggests it was taken off the case because it was not needed anymore. This is however partially refuted by figure 7.20, since it shows the excavator being productive up to week 10.

Using the GPS location of the heavy equipment to allocate other data to an area is interesting. Cross referencing values from table 7.3 to figure 7.16 there appears to be the least efficiency in area 1. This is supported by high amounts of articulated trucks in this area, which in many cases have to wait on other heavy equipment to do their work. Figure 7.17 suggests that the center of the case needed less attention from heavy equipment as time moved on. The visualization is somewhat misrepresenting as the articulated trucks have dedicated areas for parking, and their location is only given at the time of their last reported location. As the heavy equipment is configured to report their latest data on startup, they all appear in the same spots. This is however not true for the excavators which are left where they are at the end of the day. But it gives a greater perspective of which areas are being worked on, compared to the other maps.

Figure 7.18 and table 7.4 show that tracking the payloads of areas can be insightful. There were unfortunately few heavy equipment at the project with telematics capabilities for registering payloads, but they are sufficient as a proof of concept. If the whole fleet had been equipped with capabilities for registering payloads, the actual mass transport can be calculated quite easily. This is done by looking at the articulated truck payloads. The excavator or wheel loader payloads are less suitable because of other general movements of mass. Table 7.5 demonstrates this as area 2 is an area with only excavators. It therefore has a much higher amount of cycles than area 1 which consists of articulated haulers. The same effect can be observed in figure 7.19 where the excavator is registered with a payload much greater than the other heavy equipment types. This excavator is the same as was discussed earlier, and was taken off the case during week 10. This is confirmed a second time by figure 7.20. One of the benefits of third-party telematics hardware is the added functionality. The fastest intervals of CareTrack and VisionLink are daily, so it would still only give a general impression of what area each machine operates in. TrackUnit supplies hardware units that can track data down to the minute. This would enable a more continuous tracking of heavy equipment movement patterns, and I see application for it in articulated trucks. By tracking paths of the articulated trucks you could get better insight into where aggregate material should be stored at given times to optimize the travel distances.

A somewhat unexpected find was the implications of figure 7.21. The implication that heavy equipment idle less as it gets warmer is probably decided by a number of factors. When it is colder the engines need more time to warm-up. This would at most add a few minutes extra to the time, while the figure implicates a weekly 10 hour difference in idling per heavy equipment. Disregarding week 16 and 17 because of easter holiday would remove the two warmest weeks, and the line would probably not be so steep. There is still a big difference between cold and warm temperatures, which would suggest that there s some truth to the hypothesis of operators keeping the engine running to keep warm. Alternatives to warming the heavy equipment could be to install an electrical heating device in the cabs. This will reduce the idling costs and following environmental emissions.

Providing workers on-site with telematics data should be considered. Most construction barracks these days have some form of screen in the public spaces. Using these screens as a type of BIM-kiosk to transmit data about the idling hours of operators could incetivize internal competitions, like it did for Heldal Entreprenøren AS. This would however be somewhat problematic as the operator shifts occur on Wednesdays, and the reports are from mondays to sundays. Its a minor issue that could be turned into a team effort around each heavy equipment.
Figure 7.23 also shows fuel cost applied to the fuel data, and it shows there are significant sums of money generated over time from idling. By putting the fuel use into other perspective, the severity of certain issues can be transmitted better to the operators.

With the gradual technological advancements in fuel technologies and stricter emission standards, heavy equipment will move away from diesel as fuel. It is not a question of *if*, but *when*. Telematics will still be as relevant for optimization of these equipment, but the focus will probably be different than what we see today. The amount of idling will probably not be as relevant in terms of savings, and emissions from fuels will eventually be considered negligible.

8.3 Telematics data in the procurement process

A desire from Skanska is to stay competitive in future procurement processes. There was a question of whether telematics data can be of used for providing documentation of for future procurement processes. Since this is the case, and telematics data can be included as life-cycle costs, the question then becomes which data that would include. With the data I have looked at, relevant parameters suited for life-cycle costs would be connected to estimating the lifetime operating expenses of a project.
The automated data collection method could also be of some value to future procurements. By regularly recording the data at a project it can provide historical data for tendering processes. It can also provide the latest data for documentation being demanded during the execution phase, like that of the BVP method.

8.4 Sources of error

Two heavy equipment were moved out of the case. The first being a Volvo 745 articulated truck that was moved to Skanska's offices at Skedsmokorset, and the second being a 740 articulated truck that was moved to Steinkjer. They both have negligible registered hours, as they appear to not have been used for the weeks outside of the case. It is then reasonable to assume that they had no significant impacts on the data sets.

9 Conclusion

This thesis looked at how telematics data from existing telematics capabilities can be used. The research questions (Chapter 4) will now be answered. The sub-questions will be answered first, after which a final conclusion can be given on the main questions.

1.a **To what degree can the data collection process can be automated?**
The collection of data from heavy equipment telematics can be fully automated through the use of existing telematics.

1.b **Can mixed fleet telematics be a collaborative effort?**
Mixed-fleet telematics can be a collaborative effort, both between the heavy equipment manufacturers and the contractors at the project.

2.a **What optimization aspects are there?**
There are several ways to use the data for optimization:

- Monitoring the idling and fuel consumption rates can give clear indications of operator issues and equipment application problems.
- Allocation of assets based on their location can be used to give further insight into the productivity and efficiency of areas on the site.
- The data can be used to provide better predictions of the future trends.

2.b **What environmental aspects are there?**
Environmental applications of the data are related to allocation of emissions through fuel consumption. This can be done to parts of, or the whole site.

2.c **In what ways can heavy equipment telematics be of assistance on-site?**
Providing the telematics data to equipment operators can give them insight into what their bad habits are, so that better performance is encouraged. This can be done by providing an on-site telematics-kiosk.

3.a **Can equipment data be used for documentation?**
Yes. Life-cycle costs can be applied to viable data and included in the procurement process.

3.b **What telematics data are relevant for future procurements?**
Fuel use and machine hours can be included for more accurate estimations of labor and equipment costs. Environmental impacts can be included by life-cycle costs if they can be calculated.

With the sub-questions answered, a final verdict on the main questions will now be given.

1. **In what way can data from the heavy equipment be collected more efficiently?**
   More efficient data collection can be achieved by including data from different telematics providers and contractors at the project, to get a more complete view of the site.

2. **What uses can be made from the data results from Rv. 3 /rv. 25 Løten-Elverum?**
   The principal uses of the data are monitoring trends relating to the follows data:

   - Fuel consumption
   - Machine hours
   - Productivity
   - Allocation

3. **How can heavy equipment telematics be of use to future procurements?**
   Telematics data can be used to give better estimations in future procurement tendering processes. By applying life-cycle costs to viable telematics data, contractors can quantify their performances and environmental impacts to be applicable as documentation in future procurement processes. This will ensure better competitive bidding. It can also provide documentation throughout the execution phase, which is requested by the BVP method.

10 Recommendations

Through the work of this dissertation there has been gained new knowledge, wisdom, and insight. This chapter will be spent sharing my thoughts on what Skanska should do now, and what further work can be applied.

10.0.1 Advice to the client

I would like to state the following advices to Skanska:

1. Consider making an effort to have active telematics systems on all your heavy equipment. Having only parts of your fleet covered is still relevant however, as it provides some insight into the workings of the bigger fleet. But by seeing to it that the whole fleet on a project has active telematics systems you make the best effort at mirroring reality. Which will be better for site optimization and future procurement processes.

2. As briefly covered in this thesis there are several ways of making telematics more convenient. Even though my automation method is convenient because of its inexpensive nature and reliability on existing telematics, I would consider third-party telematics providers as a good option. I am then talking about using third-party software to collect telematics data from the heavy equipment manufacturers.

3. Consider having open dialogues about the telematics data with other contractors that make up a project equipment fleet. Making a mixed equipment fleet collaborative will benefit every participant as friendly competitions can encourage better results.

4. Show the weekly amounts of idling hours for each heavy equipment on a screen at the barracks. Pick the equipment with the lowest amount of idling hours as a winner each month, and hand out a team price to the individuals that operated it. This incentivizes friendly competition and is almost guaranteed to save a significant amount of money on fuel expenses.

10.0.2 Further work

One of the most appealing ways to go from here would be the development of a method for calculating life-cycle costs of heavy equipment, for the use in procurement documentation. A form of *life cycle calculator* method can probably be developed in Power BI. The application of it would be to calculate life-cycle costs of selected map areas directly, through additionally added data about the machine based on its model.
A similar approach could be to look at the possibilities of using telematics for LCA. A possible application would be to perform economic allocations based on selected areas in a map.

Another interest would be the development of a simple software that uses manufacturer provided API. Such a tool could probably be realized through the Python programming language. The software can be centered around modules for each new manufacturer API that was added, and have options for visualizing and storing the data.

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A Meeting reports

The following is a list of reports from meetings with internal supervisor, external contacts in Skanska, as well as other persons of interest. The reports can be found in appendix folder A.

- 15.01.2019 - UiA: Paul
- 18.01.2019 - Skanska: Astrid and Katrin
- 29.01.2019 - UiA: Paul
- 30.01.2019 - UiA: Reyn
- 05.02.2019 - UiA: Paul
- 15.02.2019 - UiA: Paul and Roman
- 19.02.2019 - UiA: Paul
- 26.02.2019 - UiA: Paul
- 19.03.2019 - UiA: Paul
- 10.04.2019 - Skanska: Astrid
- 16.04.2019 - UiA: Paul
- 30.04.2019 - UiA: Paul
- 03.05.2019 - Skanska: Astrid and Katrin

B Preliminary report

To view the preliminary BYG507 report, see appendix B in the appendix folder.

C Timetable

See Appendix C in the appendix folder.

D List of heavy equipment

A list of heavy equipment at Rv. 3 /Rv.25 Løten-Elverum. It is a is a document of multiple pages, and has therefore been placed in the appendix folder. It defines the equipment owner, date of commence, work area, and equipment model for each vehicle.

E Idling criteria

The following tables are mappings performed by Runar Rostad, chief of heavy equipment at Rv. 3 /rv. 25 Løten–Elverum. They provide insight into what criteria different equipment have for recording idling.

Betingelser for registering av tomgangstid

	Servospak	Hydraulikk	Girvalg	Bremser	Tomgangsturtall	Hastighet
Cat gravemaskin	E mod Uavh. av stilling	Ikke bruk av hydraulikk				
Hitachi gravemaskin		Ikke bruk av hydraulikk				
Volvo gravemaskin		Ikke bruk av hydraulikk				
Cat bulldoser D6T Steg III B		Ikke bruk av hydraulikk	Neutral / Park	Ikke betjent fotbrems		
Cat bulldoser D6T Steg IV		Ikke bruk av hydraulikk	Neutral / Park		Ikke mer enn 2% gasspådrag over 1 s	
Cat bulldoser D8T – D11T		Ikke bruk av hydraulikk	Neutral / Park			
Cat leddumper		Kasse i flyt eller hold	Nøytral	Ikke betjent fotbrems		0 km/t
Volvo leddumper			Nøytral			0 km/t

Betingelser for at automatisk stopp ved tomgang skal skje

	Ventetid	Temperatur	Servospak	Annet	Turtall	Regenerering	Display info
Cat gravemaskin	Stillbart	Uteluft 0-30 grader Fabr inst	av		Turtall ikke endret innenfor tidsintervall		
Hitachi gravemaskin	Stillbart		Av (er den på må kjører stoppe selv)	Løftevarsling deaktivisert		Om regenerer utsettes tidsintervall nedtelling til etter dette	
Volvo gravemaskin	2-50min		Av		Turtall ikke endret innenfor tidsintervall	At motor ikke regenererer	Fører Ikke avbryter hendelsen
Cat bulldoser							
Cat leddumper							
Volvo leddumper	Stillbart	Kjølevann har viss temperatur		Funksjon stopp etter nedkjøling ikke aktivisert	Turtall ikke endret innenfor tidsintervall	Stopper motor også under regenerering. (Ikke heldig)	Fører Ikke avbryter hendelsen

F Automation manual and telematics data

The following documents can be found within appendix folder F:

- F.1: A written manual on how to set up the automation method presented in section 7.1.
- F.2: Folder containing data used to generate results for section 7.2. The content is structured and named in accordance with figure 6.4.

G CareTrack manual

The Volvo CareTrack manual is a document of multiple pages. It is therefore to be found in the appendix folder.

H A3-poster

The A3-poster can be found in the appendix folder.