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A qualitative assessment of performance monitoring systems acting as an automatic data collection system in the context of productivity measurements on excavator loading operations in construction.

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Submission date: June 2018
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Preface

This thesis was worked on and concluded during the spring of 2018 as final work for the civil engineering education at the Norwegian University of Science and Technology. The thesis accounts for 30 credits and is carried out in connection with TBA4935 Construction Engineering at the Department of Civil and Environmental Engineering NTNU.

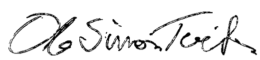
The thesis is concerned with exploring the potentials of PM systems acting as an automated data collection system with the purpose of *productivity improvement* and *progression control* on excavator operations. Initial interest on the topic came to light during a pilot study which surveyed the field of research on the topic of productivity in construction. In cooperation with my guidance counselor, Amund Bruland, the feasibility of the study was discussed, and it was deemed a pre-study effort should be made to investigate further before engaging the topic any further. The pre-study consisted of manually searching the entire register of the journal Automation in Construction as well as an examination of Olsen, V. (2009) and Johannessen, O. (1992). The pre-study revealed that there was indeed sufficient material to justify further research on the topic. It was decided another literature study was necessary in conjunction with interviews of field experts, system providers, and contractor management. Also, a document study of PM system produced reports was deemed necessary.

I would like to extend special gratitude to Amund Bruland for providing unwavering standby counseling when obstacles presented themselves during the work. In addition, Bruland established initial contact with field expert Njål Hagen from Marskingrossistens Forening which initiated the process of data acquisition for the interviews and document study. Njål Hagen also receives my gratitude for outstanding cooperation in the initiation phase of the thesis.

A special thanks to Per Ola Berntsen and Stian Lund at Sitech Norway for providing me with excellent information and connections to crucial participators that were needed to proceed with the study. Hans Petter Dæhli also deserves a special thanks for unparalleled cooperation as one of the first links in the effort of establishing contact with key actors in the industry.

Lastly, well-deserved gratitude is directed towards my fellow students Haakon Rolfsfjord, Andreas Skui Nøklebye, Duy Tien Trinh and Maja Worren Legernæs which provided me with feedback and favors during the semester.

Trondheim, June 2018



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Summary

The manufacturing industry has arguably spearheaded the progress of productivity monitoring and optimization with several proven concepts. The construction industry has been known to borrow and adapt many of these concepts in various forms in an effort to likewise improve upon their productivity. However, AEC-projects is accompanied by complex causality relations not only between different participating contractors but also between design and production teams. Typical AEC-project conditions impose many influencing factors on the total productivity of said project, and to understand, control, monitor and improve the processes there has been developments in strategies and systems on activity level. By excluding the human interaction with the data collection, the enterprise of Automated Data Collection(ADC) was established. ADC systems have two fundamental dimensions of requirements; the ability to produce a certain set of parameters; and a certain set of characteristics enabling the system to provide the correct data reliably. Localizing efforts of measuring productivity on activity level gives opportunities to isolate the measurements from possible unknown influencing factor thus rendering the comprehension of the underlying reasons for either promising or failing productivity attainable.

The majority of research on this topic seems to consist of standalone solutions such as visual recognition systems and inertia systems to determine specific parameters needed for calculating productivity measures. There are however commercially available options which have the potential to do the job, Performance Monitoring(PM) systems, for instance, are systems which allows contractors to monitor their construction equipment fleet. Such PM systems collect data through the Legacy Engine System(LES) and are provided by the Original Equipment Manufacturer(OEM). The purpose of such systems is to provide the client with valuable information regarding the status of their equipment fleet.

In light of the conditions mentioned above, and in the absence of similar research this thesis is concerned with determining the details of the capabilities of PM systems in the context of ADC and productivity measurement on construction excavators performing loading cycles. This rather strict scope enabled more specific and precise requirements for the PM system to be qualitatively judged by.

Preceding this thesis there was conducted a pilot study on the topic of inaccuracies in construction productivity where a total of 117 articles was evaluated and studied. The *"gaps"* in research discovered in this pilot study lead to the topic at hand. There was launched a pre-study on the outset followed by a comprehensive literature review with a finalized literature pool of 32 state-of-the-art articles. The literature review built a foundation upon which a document study of PM client reports and several interviews with contractor and field experts were conducted.

The study establishes the requirements needed of ADC systems if they are to sufficiently provide the parameters needed for the calculation of productivity on construction excavators. The comparison of these requirements and the findings of the document study revealed that current PM systems lacked requirements in several areas. The PM systems were found not to provide the user with the parameter quantity of mass, and some PM systems lacked satisfactory categorized activity modes. Crucially the PM systems lacked several of the crucial characteristics of an optimal ADC system.

The study concludes that the current state of PM systems does not provide the client with sufficient information and cannot, unaltered, be used as an ADC system with the intent of measuring construction productivity on excavators due to several identified reasons. There are however several promising findings surrounding the limitations of the PM systems studied which enlighten the topic for future research.

Sammendrag

Produksjonsindustrien har uten tvil vært den banebrytende aktør når det gjelder fremgangen i produktivitetsovervåking og optimalisering, med mange fungerende konsepter. Byggebransjen har adoptert og tilpasset mange av disse konseptene i ulike former for å forbedre produktiviteten i bransjen. AEC-prosjekter er imidlertid ledsaget av komplekse årsaksforhold, ikke bare mellom ulike entreprenører, men også mellom designteamet og utførende aktør. Typiske AEC-prosjektforhold bringer med seg utallige påvirkningsfaktorer som spiller inn på prosjektets totale produktivitet, og i et forsøk på å forstå, kontrollere, overvåke og forbedre prosessene har det vært betydelig fremgang i utviklingen av strategier og systemer på aktivitetsnivå. Ved å utelukke det menneskelige elementet i datainnsamlingen, ble samleutrykket "automatisert datainnsamling" (ADC) etablert for systemer som automatisk samler data. ADC-systemer har to grunnleggende dimensjoner av krav; evnen til å produsere et bestemt sett med parametere; og et bestemt sett med egenskaper som gjør det mulig for systemet å gi riktig data pålitelig. Ved å fokusere målinger av produktiviteten på aktivitetsnivå, åpner man for muligheten til å isolere målingene fra ukjente påvirkningsfaktorer, og dermed kan en dypere forståelse av de underliggende årsakene til enten lovende eller sviktende produktivitet oppnås.

Mesteparten av forskning på dette emnet ser ut til å bestå av frittstående løsninger som visuelle gjenkjennelsessystemer og momentkraftssystemer for å bestemme visse parametere, som er nødvendige for å beregne produktivitetsmål. Det eksisterer imidlertid kommersielt tilgjengelige alternativer som har potensial til å gjøre jobben. Prestasjonsovervåking (PM) -systemer for eksempel, er systemer som gjør det mulig for entreprenører å overvåke maskinparken. Slike PM-systemer samler data gjennom Legacy Engine System (LES) og leveres av originalutstyrsleverandøren (OEM). Formålet med slike systemer er å gi klienten verdifull informasjon om statusen til maskinparken deres.

I lys av det ovennevnte, og i fravær av lignende forskning, har denne oppgaven som formål å utbrodere hvilke funksjoner PM-systemer er egnet til i sammenheng med ADC og produktivitetsmåling på gravemaskiner. Omfanget gjør det mulig å spesifisere klare krav som PM-systemet kvalitativt vurderes i henhold til.

Forut for denne oppgaven, ble det utført en pilotstudie rundt emnet om unøyaktigheter i byggeproduktivitet, hvor totalt 117 artikler ble evaluert og studert. Pilotstudien identifiserte hull i forskningen som førte til denne oppgavens formulering og formål. Det ble gjennomført en forundersøkelse etterfulgt av et omfattende litteratursøk og litteraturvurdering. Litteratursøket resulterte i 32 state-of-the-art artikler som etablerte grunnlaget for en dokumentstudie av PM-klientrapporter og flere intervjuer med entreprenør- og felteksperter.

Studien etablerer kravene til ADC-systemer, gitt at de skal levere de parameterne som trengs for beregning av produktivitet på gravemaskiner. Sammenligningen av disse kravene med funnene fra dokumentstudien, viste at dagens PM-systemer manglet krav på flere områder. PM-systemene gir ikke brukerne mengde masse, og noen PM-systemer manglet tilfredsstillende kategoriserte aktivitetsmoduser. Det viktigste funnet var at PM-systemene manglet flere av de avgjørende egenskapene som kreves av et optimalt ADC-system.

Studien konkluderer med at dagens PM-systemer ikke gir kunden tilstrekkelig informasjon og at de ikke uendret kan brukes som et ADC-system med formål om å måle produktivitet på gravemaskiner på grunn av flere identifiserte årsaker. Det er imidlertid flere interessante funn koblet til begrensningene i PM-systemene som ble studert, som peker på potensielle emner for videre forskning.

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Abbreviations

AEC	=	Architectural, engineering and construction
ADC	=	Automated data collection
PM	=	Performance monitoring
MCS	=	Machine control system
CLP	=	Construction Labor Productivity
TFP	=	Total factor productivity
MFP	=	Multifactor productivity
SFP	=	Singel factor productivity
KPI	=	Key performance indicator
PI	=	Productivity indicator
IF	=	Influencing factors

CHAPTER

ONE

INTRODUCTION

The following chapter presents the circumstances behind the choice of scope and objectives as well as some of the limitations that come with it. Furthermore, the specific purpose and objectives are stated in addition to a readers guide which clarifies any choices made regarding the structure of this thesis.

1.1 Background

There has undoubtedly been conducted assessments, estimations, and measurement of productivity in one way or another since the dawn of civilization. With the emergence of modern civilization the purpose of being productive was no longer about surviving, but prospering and in the context of companies and competition, prosperity is all about net profit. With profitability and technological progress in mind, the industrialization and innovations like the T-Ford assembly line were arguably inevitable. The manufacturing industry pioneered productivity progression and eventually developed several *lean* concepts(Moore, 2007). Most manufacturing processes produce units that are finalized in a relatively short duration and thus is repeated continuously to produce large amounts of the same unit. In a rudimentary example the size, location, and other conditions are constant, which presents an obvious space for incremental improvements to optimize the process. A quantitative approach to such an environment can, given the right application, produce sound conclusions about the optimal production processes. The construction industry, however, works with specialized units, longer production cycles, less predictive conditions and a temporary organizational structure with parties that potentially have questionable and conflicting motives. This makes the environment for productivity measurement in AEC-projects far more complex.

Preceding this thesis, during the autumn of 2017, a pilot study on the topic of productivity measures and their inaccuracies were conducted. Although not the main objective, areas lacking attention in the current field of productivity research was charted. As a means of reaching its main goal, the study identified several of the prominent influencing factors affecting productivity. Most of these being results of human interactions. In the context of industrial production, these human interactions are surrounded by a stable and comprehensible environment which is certainly not always the case in AEC-projects. Furthermore, for a large number of manufacturing companies, the production is also performed by automated machines. These conditions are at least partly the reason why the industrial sector is so far ahead regarding automated control and systems enhancing productivity. Adoption of systems benefiting the manufacturing industry has been attempted but as mentioned the environment does, in most cases, not allow for a clean implementation. Adoption of altered systems inspired by manufacturing concepts such as; *building information modelling*(BIM); *Lean construction*;*Last Planner*; *supply chain management*; *Level of development*(LOD) has been attempted, in most cases with promising results. Although less prominent in the field of research, automation of productivity measurements seems to be a natural addition to this list. Navon (2007)argues that there is, in fact, a lack of attention on the subject of *automated data collection*(ADC) regarding progress and productivity. Most of the potential in researching this topic lies in that the process of performing manual measurements are expensive, time-consuming and are subject to several potential human errors (Pradhananga & Teizer, 2013; Memarzadeh et al., 2013; Navon, 2007; Azimi et al., 2011; Azar et al., 2013; Viljamaa & Peltomaa, 2014). For any automated system to be beneficial, it would, therefore, need to be robust, flexible in its inputs, and be affordable.

Due to AEC-projects consisting of several processes that have vastly different qualities, ADC systems need to be tailored to the specific processes being monitored. In accordance with this and the effort of narrowing the scope, the chosen process to be investigated is earthmoving operations. Furthermore, the scope is to only consist of the systems concerned with excavators. Another benefit to this confinement of the scope is that the sheer volume of physical work earthmoving operations performed during most AEC-projects provides a considerable motivation for its improvement. The quantity in these operations also prompts concerns about the accuracy of the measurements. In context with ADC systems, the aspect time sensitiveness of such data also presents itself. When deviations from planned progress discovered or other indicators are not met, identifying this in time is crucial. Corrective measures need to be employed early for maximum effectiveness. This makes a *real-time*(RT) measurement of considerable value. In construction, RT is defined as equal or greater than 1 Hz data update rate(as cited in Pradhananga & Teizer (2013)). An update rate this *"excessive"* is in most instances not needed and is bound to be expensive in some instances. Corrective action can be made in near-real-time(NRT) and is arguably sufficient. What constitutes NRT is hard to define, due to it being dependent on what is being measured. However, hourly update rates would be sufficient in almost every scenario connected to earthmoving operations with excavators.

In summary, there is a lack of research on the topic of ADC systems on construction equipment and its potential concerning productivity and production optimization. The dimensions that seem to be of particular importance is that the system exhibits characteristics such as *automatic, NRT, robustness, economy and accuracy*. There seems to be available avenues of research to this end and if it were to be taken advantage of it is safe to assume that it presents opportunities for productivity improvement. Vast efforts are being directed towards exploring standalone solutions, but less effort has been made on taking advantage of existing systems. The relations between current systems, use of the available data, and its usefulness compared to fundamental productivity theory is, at least to the author, unclear. A qualitative investigation of these relations seems to be the best course of action before any valid quantitative research on the topic can be done. Along with Machine Control(MC) systems, the Performance Monitoring(PM) systems are commercially the most widespread. MC systems use geospatial data that not only provides the operator with guidance in accordance with design but also provides the contractor with useful information. However, the PM system seems to be more equipped for providing the required parameters, which is why it is chosen as the system that is to be investigated. Note that the purpose of PM systems does not seem to be aligned with the purpose it is to be judged by in this study. This means that there are definite limitations connected to the potential findings. The hypothesis is that although PM systems are mainly concerned with progression control and management there seem to be opportunities in terms of measuring and calculating productivity with the intent of exploring the opportunities it and similar systems posses.

1.2 Scope and objectives

The main purpose is to explore the potential of PM systems acting as an ADC system with the intent of measuring productivity on excavator loading operations. This goal presents a large and quite vague scope. To remedy this four research questions was developed to strategically engage the objective **(see table 1.1**).

Q1: What kind of data is collected by PM systems?
Q22: Does the collected data provide sufficient information i regards to calculating productivity?
Q33: How is data collected and used today?

Table 1.1: Research questions, formulated as a response to the pilot study and through meetings with guidance counsellor.

1.3 Limitations

Contextual limitations

The master thesis was conducted at the Department of Civil and Environmental Engineering at NTNU Trondheim in connection with *TBA4935 Anleggsteknikk, masteroppgave*. The thesis accounts for 30 credits and is limited by the time period of 15.01.2018-11.06.2018.

Scope limitations

The first and most crucial reservation mentioned briefly in the introduction, is that the purpose on which PM systems are judged by in this study is not claimed to be the sole purpose of said PM systems. In principle, that means that any lack of fulfillment of requirements set by this study does not diminish the judged PM systems on an overall basis, but rather only in the sense of their capabilities regarding functioning as an ADC system with the intent of measuring productivity for *progression control* and *productivity improvement*.

The field of research is to be narrowed to aspects of automated data collection on excavators in AEC-projects. That means any potential beneficial discoveries on other construction machinery will not be explored in detail other than its connection to the main topic. Furthermore if typical conditions of AEC-projects**(see section 3.1)** does not apply the topic will not receive any further resources. Extensive monitoring systems covering entire project performance will not be studied in detail. However, discoveries on the main topic which might prove useful in relation to such a system might be discussed briefly. Although safety is connected to productivity, safety benefits from any system will only be dealt with superficially if at all. Any quantitative methods of enhancing the accuracy of traditional calculations for cycle times, loading costs and productivity of excavators will not be explicitly researched. Note that this limitation does not diminish benefits from systems that directly provide automated parameters which might render traditional calculations less than optimal. Also, measures which indirectly indicate productivity will not be examined in full detail but rather mentioned as supplementary benefits to any system that it might be a part of. Furthermore, excavators are considered a flexible piece of construction equipment and not all possible excavator operations will be included. The study is concerned mainly with loading productivity.

There is also an important distinction regarding the term *automatic*. In this study, it is to be interpreted as a characteristic indicating that the function of said system, once installed, is performed automatically without human interaction. It is not be confused with autonomous systems or hard automation such as robotics.

1.4 Readers guide

This thesis is written using ShareLateX (*https://www.sharelatex.com/*, 2018) Online.The template used is available at ShareLaTeX online and can be found under the name *"NTNU master thesis template"*. Furthermore, it is written in accordance to guidelines available at NTNUs wiki pages (Institutt for bygg, 2018). The fundamental structure is known as the *"IMRaD"* structure. The chapter **Theory 3** is somewhat disproportional to many similar works mainly due to the exploratory nature of the scope. A significant amount of work went into exploring the field of systems and strategies to correctly assign requirements and characteristics of an ADC system designed to measure and calculate productivity on activity level.

The intended experience of reading this report demands reading the article sequentially from start to finish, as this assures a deeper understanding of the contents and its implications in context. Note that chapter 2 main body of work is confined within the attachments and the text is merely a tool for interpreting these attachments correctly.

The structure of **chapter 4, 5 and 6** is specifically designed to address the research questions in the chronological manner which they were presented above **(see table 1.1)**.

Lastly the term *"third party"* in the context of this study to be interpreted as separate from OEM services. In other words separate from the two party system of contractor and PM system provider.

CHAPTER

TWO

RESEARCH DESIGN AND SCIENTIFIC APPROACH

The following chapter addresses why and what methods are used to enlighten the objectives already established in section 1.2. The purpose of this is to establish reproducibility and to secure the most rewarding scientific approach to the task at hand.

2.1 Scientific approach

The choices of methodology when commencing a research project is of absolute importance. The failure to assimilate the most suited method of research might result in a dramatic drop in quality. Some of the most prominent classifications and methods of performing scientific research will therefore be evaluated in relation to the scope.

Quantitative vs. qualitative research

The main classification when performing research is the distinction between qualitative- and quantitative studies (Blumberg et al. 2011). Qualitative methods are concerned with making descriptive distinctions based on some quality or characteristic of an object, subject or concept. Case studies, questionnaire surveys, and literature studies are some examples of a typical qualitative method.

Quantitative methods, on the other hand, are concerned with numerical values. This seems simple enough. However, there is a distinction which is critical to understand. Numerical values can, in fact, represent a qualitative characteristic. One might study a numerical value which indicates a company's ability to compete. Isolated this value only represents the qualitative characteristic of the company's competitiveness. However, if used in, for instance, statistical analysis with a large set of data, this might constitute a quantitative argument(Bryman, A., 2012). Although some of the objectives (see **Section 1.2**) are concerned with numerical data, the purpose is to establish a qualitative description of the potential this data presents. The data is not going to be used in any quantitative methods. This distinction is important and means that the study will mainly consist of qualitative research.

Descriptive vs exploratory

Blumberg et al. (2011) also distinguish between exploratory, descriptive and causal studies. The scope is well defined which suggests a descriptive approach. However, some aspects are not known, for instance, if the existing ADC system provided data is sufficient for productivity analysis. Therefore, the study will consist of aspects from both an exploratory and a descriptive study, as the research questions indicate.

Research questions	Category
What kind of data is registered by ADC systems?	Descriptive
Does the registered data provide sufficient information i regards to measuring productivity?	Diagnostic
How is the data used today?	Problem identifying

Table 2.1: Categorisation of the research questions, inspired by (Busch, T., 2013)

Validity and reliability

Healthy research in terms of the scientific method is required to be reproducible and repeatable. At the core, this means that the findings of any research work must be testable. If this is not the case, the work cannot be verified as authentic. This concept is one of the fundamental rules of the scientific method and is commonly known as *reliability*(Bryman, A., 2012).

Secondly, any scientific work is required to prove that the claims are valid. In other words *Validity* is a measurement of the degree to which the claim could be considered a fact(Bryman, A., 2012).

Pros and cons of qualitative research

The main limitations to qualitative research are commonly considered to be author bias(Bryman, A., 2012). By performing typical qualitative research such as case studies, literature studies, surveys, interviews and document studies, subconscious bias is hard to avoid. This naturally makes qualitative research hard to replicate as well. There are however partial remedies to such problems; one can strive for a high degree of reliability and validity. For instance, by making interviewees confirm that the content of an interview report is consistent with the viewpoint they conveyed during the interview, or by documenting every step of a literature search. Although not entirely eliminating the problems with qualitative research, it lessens them to a great extent.

Quantitative research to some extent avoid several of such limitations since it, as much as possible, removes the author from the process of distilling scientific findings(Bryman, A., 2012). However, it can be argued that qualitative research of a topic is a prerequisite to most quantitative research. To correctly apply quantitative methods, one needs to understand the qualitative characteristics of the topic and its circumstances.

By applying qualitative methods to a problem, complex connections can be identified. Humans are better equipped for understanding and reasoning the nature of such complex systems. Once the topic is explored and described through qualitative methods, more systematic quantitative methods can be applied to draw a conclusion about the topic objectively. This explains why pilot studies are conducted, usually with qualitative methods while the main study usually consists of some form of quantitative analysis.

Selection of methods

To select the appropriate methods, they need to be evaluated in relation to the objectives(**see section 1.2**). **Q1** was categorised as descriptive **(see table 2.1)**. This objective is mainly concerned with what the current status of ADC systems is. A literature study on the state-of-the-art research field was deemed appropriate in order to identify the data which current systems are able to provide. Interview of several field experts was also deemed fitting. Through these experts, there was also made attempts at acquiring documents for a document study of key parameters ADC systems provide. **Q2** was categorized as a diagnostic objective. The reason for this is that it demands a comparison with fundamental productivity theory and the data that state-of-the-art systems are able to provide. A document-study of fundamental theory for calculating earthmoving operations productivity needs to be performed. Comparing the findings from this document-study and the literature search should provide valuable information in how ADC systems can provide parameters that are useful in productivity analysis.

Q3 was categorized as a problem identifying objective. This is because if the state-of-the-art progress on the topic were to its full extent taken advantage of in the industry, there would be no need for this study. In other words, the assumption that the industry is lagging behind and not taking full advantage of the state-of-the-art scientific progress is the premise of this scientific work. Although this is an assumption, it is one based in reality. The ideal *research-front* will always be one step ahead of real-world application. Interviews with AEC-project managers, site-managers, and clients of ADC systems was deemed the appropriate approach to answering this objective.

It needs to be mentioned that the literature search for example, will be beneficial to all of the objectives, while the interviews is mostly concerned with **Q3** and that the document study will be mainly concerned with **Q1** and **Q2**.

2.2 The literature search: A systematic review

Although literature searches differ in many ways, most exhibit some form of collection of literature on the basis of a set ofc hosen criteria. The pool is then cut down in size and further inspected. To establish the right way forward, an adequate model for performing the literature search has to be established. Furthermore, to produce the most effective and accurate model, the main goals and objectives have to be taken into account. This means that the assessments in terms of relevance of an article are dependant on the scope of the thesis, this might seems obvious but it presents the search process with concrete, yet subjective criteria.

Arksey and O'Malley (2005) explains that the main difference between a systematic review and a scoping study is that the systematic review usually consists of well-defined goals that can be determined at the start. A scoping study, on the other hand, is optimal when the field of study is less known to the researcher, and the scope is wider and sometimes vague. The project report *"Qualitative inaccuracies affecting the construction industry: A scoping study"*(Tveiten, O.S., 2017) was, in part, an attempt to conduct a state-of-the-art examination of the entire construction industry on the topic of productivity measurement at site-level. The literature search in the report was a scoping study which means that the wider aspect of productivity to some extent is covered and a systematic review with stricter criteria is to be performed in this thesis. This way of progressing research is argued by the Department of Computer Science at the University of Durham:

"The results of a mapping study(scoping study) can identify areas suitable for conducting Systematic Literature Reviews and also areas where a primary study is more appropriate" (Department of Computer Science University of Durham, 2007)

A systematic review: Framework

Kitchenham and Brereton (2013) presents a baseline framework for how to perform a systematic review. The framework consists of three stages and although an adequate model, a combination of different models was deemed optimal. The following framework was therefore created in order to identify and evaluate chosen research articles effectively:

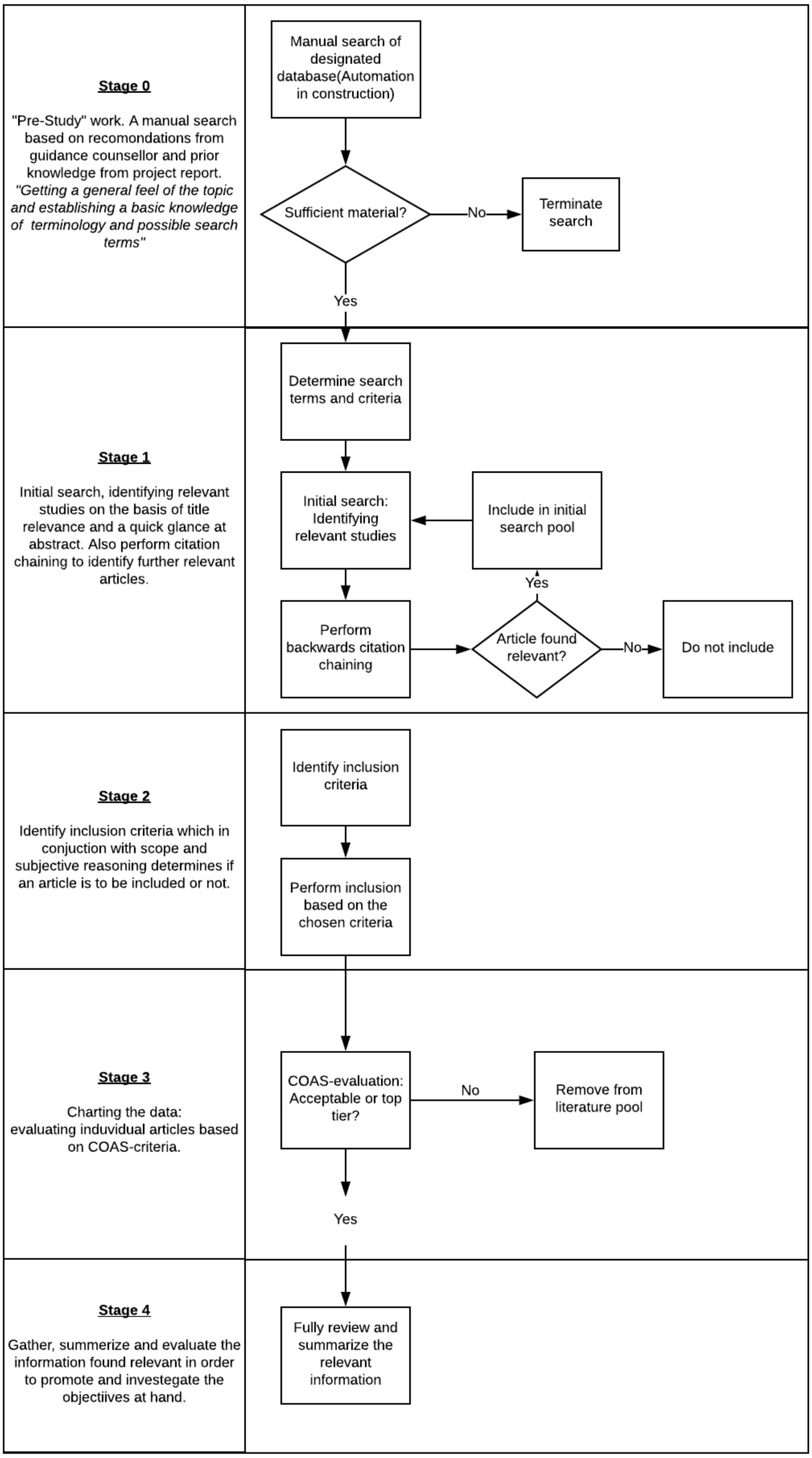


Figure 2.1: A systematic literature review framwork inspired by (Kitchenham & Brereton, 2013), (Arksay & O'Malley, 2005), (Blumberg, B. and Cooper, D.R. and Schindler, P.S., 2011) and (Department of Computer Science University of Durham, 2007)

Stage 0: Pre-study work

Through several meetings with Amund Bruland, the feasibility of the objectives established (see **section 1.2**) was discussed and found adequately productive regarding research value. The master thesis*"Evaluering av Machine Drive Power som valsemontert responsmåleverktøy"*(Torpe, E., 2017) was chosen as an entry point in order to establish some familiarity with the topic of automated data registry from MCSs. Furthermore, a manual search through the journal *"Automation in construction"* (1992-2018) was deemed the most fruitful starting point for generating the needed familiarity with search terms and general knowledge about the topic. The manual search consisted of manually scouring all the articles published between 1992 and 2018 and subjectively assessing the relevance by title. This resulted in 35 articles, which was by further inspection of the abstract and light reading reduced to a final manual search pool of 19 articles which will join the initial search pool from stage 1 **(see Attachment 1 and Figure 2.1)**. The research field proved sufficiently fruitful in terms of identifying relevant articles and stage one could be set in motion.

Stage 1, identifying relevant studies

In order to make a selection of interesting and relevant literature, the search engine that presents the most benefits must be determined. In accordance with previous experience in literature study as well as by advice of guidance counselor, the literature study will rely on a few specific search engines. This also ensures a higher reproducibility.

Google scholar

This search engine gives a wide variety of hits which is preferred when building a comprehensive and broad basis for selection. More than any other search engines it ensures large amounts of hits due to the amounts of databases it possesses. This, however, demands the right input, which can be hard given that Scholar is known for withholding its search algorithms. This means that hitting the article you want is likely if the right input is made, but this not the case when initializing a literature search. Also, scholar offers few restrictions on the search which leads to unprocessable amounts of hits unless the right string of search terms is used. Furthermore, the fact that scholar is withholding its search algorithms means lowered reproducibility of the search.

To summarise Google Scholar will explicitly be used for quickly revisiting an article already identified by the chosen main search engine. Also, the scholar profile search function will in some instances be used to check credibility of certain authors.

Engineering Village

Engineering Village is a more controlled search engine, with 17 different databases that offer access to trusted engineering literature. As a student of NTNU, access was gained simply by navigating Oria.no while being logged into the school servers. Compared to Google Scholar the hits are more secure due to trustworthy sources (Elsevier: B.V., 2017). Searches made in Engineering village shows only hits in the chosen tag. The tags are as follows: title/abstract/subject; abstract; author; author affiliations; subject; CODEN; conference information; collection title; ISBN; ISSN; publisher; source title; patent number; controlled term; uncontrolled term and country of origin.

Note that search results will be restricted in comparison to Scholar due to search results being determined by tags. One could argue that this does not make a difference since using the right tag will result in a hit given that the work exists in the database. If the work is found in Scholar and not in Engineering Village one could conclude that the work isn't in the database. However the tags are not represented in all the databases covered by Engineering Village, this means certain searches will not show hits that exist since the tag is not compatible. These potential hits will be excluded from the search results even though they exist within the databases.

The comprehensive tag system ensures reproducibility, which is crucial and in combination with credible databases and an easy to use interface, makes Engineering Village the best choice.

Scopus

Scopus was evaluated for use as the main search engine to be used during the literature search but was deemed to be too cumbersome due to large amounts of non-construction and engineering related scientific content. Normally this would not be a problem, but in this instance, a more specific database of content provides easier access to the relevant articles through a literature search. Other than that Scopus in many ways provides similar virtues as Engineering Village.

Although Scopus was not directly used for the literature search, Engineering Village gathers citation number for each article from Scopus. This makes Scopus an indirect source of information in the literature search.

Search terms and filters

Search terms

By both considering the stage zero manual search results and Eirik Torpe's (2017) thesis an initial subjective choice of the search terms was made. This was based on rudimentary knowledge of the topic and how the Engineering Village search engine works. The initial search terms are as follows: *Machine, control, system, performance, monitoring, computer, parameters, excavator, automation, construction, earthwork, productivity, measurement, loading* and *production*.

These are single words which isolated cannot produce relevant search results, but combining them in different variations proved extremely potent.

Search tags

Tags, as discussed while evaluating the search engine Engineering Village, determine where the search terms are put to effect. The tag was chosen out of simplicity and is as follows: *Subject/title/abstract*. Although this tag does not cover all the databases in Engineering Village, it ensures more specific results with the main restricting factor being the search terms themselves and their combination. Also from experience, this tag effectively narrows the search while simultaneously ensuring relevance due to the title and abstract being included.

Search filters

The search filters were determined on the basis of credibility and for simplicity. the search filters were as follows: *English, Journal article* and *No Duplicates*.

The Engineering Village is in many ways already trustworthy regarding credibility, but confining the results to journal articles furthers the credibility by making the results consist of peer-reviewed material. Although conference articles were evaluated not to be included as a search filter due to some variation in quality, some were included due to backward citation chaining **(see section 2.2)**. Note that Search codes found in **Attachment 2** are only compatible in the *Expert* search mode. Furthermore, the *No duplicates* filter are added last and implemented on the search with the following criteria: *Field of preference: Has full text* and *Database preference: Compendex*.

Selection

The initial selection consisted of a plain subjective evaluation of the title. The titles ability to peak interest and potential to be of relevance when answering the research questions was the deciding factor when selecting the initial search pool. Being that this search was not the most comprehensive of sorts, a quick glance at the abstract was also part of this process, although the main criteria for inclusion were the title. Inclusion of an article was documented in an Excel chart **(see Attachment 2)**.

Backwards citation chaining

As **figure 2.1** shows, an early citation chaining process was deemed appropriate in order to determine potential search terms and topics which might have gone under the radar during the pre-study stage. The backward citation chaining or ”snowballing” consisting of analyzing the reference section of the already identified articles. Articles peaking subjective interest regarding relevance to the objectives WAS further investigated and added to the search pool if evaluated to be of importance. There was added 12 articles as a result **(see Attachment 3 and 4)**.

Stage two, Study selection

Criteria

The inclusion criteria were customized to fit the scope of the study. With the capacity available, a succession of easily determined criteria as follows was the criteria used to reduce the pool size: *Title, Keywords, Abstract* and *General relevance*.

If the article in question peaked interest in relation to the research goals and main objective on all accounts, the work was ”accepted”. This means the work was approved for further inspection in stage three**(see Attachment 5**.

Stage three, Charting the data

Stage three of the literature study consisted of subjecting the accepted hits to closer analysis. At this point, the entirety of the article was read. Although the article in its entirety was read, its content was not studied in-depth. The point was to detect whether or not the article consisted of relevant information, as well as its credibility. Charting the data consisted therefore of logging valuable data such as:

- Standard bibliography inputs, i.e., Author, year of publication, title, location, source, etc.
- Goal/scope/aim of the study
- In-depth evaluation of credibility, objectivity, accuracy, and suitability.

COAS-evaluation

By conferring with several sources, and mainly a video posted on NTNU’s pages regarding the critique of sources(NTNU.edu: Wiki, 2017), the evaluation of each article went through a thorough process of evaluation with the following criteria: Credibility, Objectivity, Accuracy, and Suitability.

Each criteria was evaluated on a scale from 1-3; 1 being *Not acceptable*; 2 being; *Acceptable*; 3 being *Top-tier* **(See figure2.2)**. This step provides quality assurance. It became clear however that some steps, such as using the right search engine, and basic reasoning when reading the abstracts to some extent filtered out articles which might have scored badly in this evaluation.

28	Pertinent data					
29	Title + (# citations in Scopus)	Author(s)	Year	Source	Type document	Acquisition	Scope/goal
30	Prediction-based stochastic dynamic programming control for excavator (0)	Hua Zhou Peng-Yu Zhao Ying-Long Chen Hua-Yong Yang	2017	Automation in Construction, Elsevier	Journal article	Manual pre-work search - Automation in Construction	"Because the fuel efficiency of excavators is low and the energy loss is considerable, a prediction-based stochastic dynamic programming (PBSDP) control strategy is proposed in this study to reduce the energy and fuel consumptions. Using the torque prediction method, the optimization control strategy can be used in real time to improve the fuel efficiency."

31	COAS - Evaluation			
32	Criteria	Score	Justification	Final score
33	Credibility	3	Hua Zhou: State Key Laboratory of Fluid Power and Mechatronic Systems, Zhejiang University, Hangzhou Peng-Yu Zhao: State Key Laboratory of Fluid Power and Mechatronic Systems, Zhejiang University, Hangzhou Ying-Long Chen: State Key Laboratory of Fluid Power and Mechatronic Systems, Zhejiang University, Hangzhou Hua-Yong Yang: State Key Laboratory of Fluid Power and Mechatronic Systems, Zhejiang University, Hangzhou Credible publisher	3: Top-tier
34	Objectivity	3	Evaluated to be objective, clearly states the papers limitations and achievements in objective terms	
35	Accuracy	2	Based off of simulated results, real experiments/testing not provided	
36	Suitability	3	Certain parameters needed for fuel saving might prove useful arguing the automated collection of such data	

Figure 2.2: COAS-evaluation matrix

Literature search quantitative results

The literature search

Stage 0 identified 19 articles. Stage 1 produced 27 articles(**see Attachment 2**). Combined this produced a pool of 46. By utilizing backward citation chaining additional 16 articles were added. The total number of articles became 62. Stage 2 reduced this to 32 by excluding the ones that did not meet the required criteria. The exclusion process was part of stage 2: study selection.

The evaluation of quality

The finalised literature pool of 32 articles **(see Attachment 5)** moved to stage 3, charting the data. This stage as described by **section 2.2** consists of a quality evaluation. By evaluating each article on the basis of four criteria the articles were either deemed top-tier, acceptable or not acceptable. The evaluation deemed 29 articles top tier and 3 acceptable. The reasoning behind the high scoring in stage 3 needs some exploration. First of all, the articles which are contained within Engineering Village's databases has already passed quality control (Elsevier: B.V., 2017). Furthermore stage 2, trough the process of subjectively assessing the articles against criteria, also provided valuable validity and relevance security. This means that when the literature pool was finalized it had already passed subjective, but reasoned, credibility checks due to an evaluation of the title, abstract, , and general relevance.

Limitations

In general, a literature-study has many limitations. First of all the actual interpretations of the chosen articles and scientific work might be wrong. This can, of course, be avoided for the most part by close study of the scientific work in question and conferring with the project guidance counselor. Furthermore, it was discovered through the pilot study and also this literature study that, in fact, the chosen framework for selection and evaluation of the articles yielded promising reliability and validity.

2.3 Interviews

Bryman argues in his book, *"Social research methods"*(2012), that the interview is probably the most used method when it comes to qualitative research. Although this is not a good argument for the use of this method, it nevertheless appeals to its flexibility. Bryman distinguishes between the *Structured interview* and the *qualitative interview* where the latter is further divided into the *unstructured* and the *semi-structured*. The structured interview is most advantageous when interested in quantitative sampling. Rigid and reproducible results are what matters. When considering qualitative interviews, it is considered favorably if the interviewee rambles, goes off on tangents and so on. By letting the interviewee talk about what comes to mind can potentially capture their unique point of view on the subject.

A semi-structured interview was deemed most fitting since it allows for the interviewee to contribute unique perspectives and it also provides some boundaries realized by an interview guide. Most of the interviews were done in a meeting with the person of interest, although some were performed digitally via e-mail. This is clearly stated in each interview report. The interview guide was established in context to the objectives, and in accordance with guidelines promoted by Bryman, (2012):

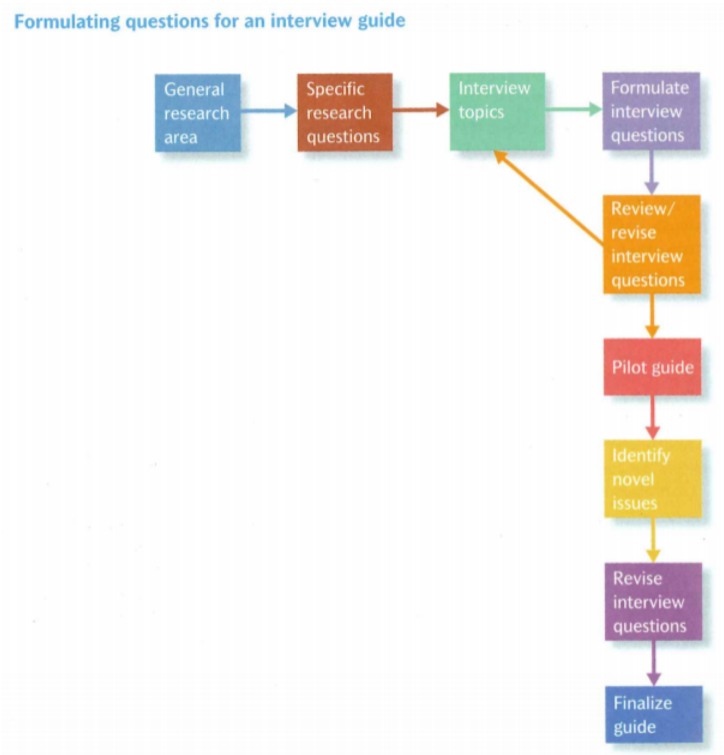


Figure 2.3: Formulating questions for an interview guide, (Bryman, A., 2012)

The interview process

Several meetings with guidance counsellor Amund Bruland during the pre-study stage revealed a lack of connections in terms of possible interviewees. It was decided a so called *"Snowball sampling"* (Bryman, A., 2012) was to be used. Snowball sampling refers the technique of starting with a small sample group and extending this group by further reference of the participants. Amund Bruland assisted with initial contact in this snowball sampling process. Njål Hagen at Maskingrossisternes Forening (MGF) was considered an optimal starting point. The snowball sampling worked as intended and lead to several interviews with key parties in the industry. **(See attachments 7, 8, 9, 10, 11, 12 and 13)**

The interview guide

The interview guide**(see attachment 14)** was considered important in order to establish a basis for performing the interview. Since the chosen category of the interview was the semi-structured one and interviewees with different occupations, the interview guide needed to be flexible and open for deviations.

Rules for the interviews

The timespan, purpose and other relevant information are to be made clear to the interviewee before asking any questions. Furthermore, the interviewee is allowed to digress as long as the topic is within

Field experts and System providers	Management
What systems are available to costumers today?	What kind of data is available to you through machine control systems?
How do these systems operate and what functions are available?	What is the benefits of such systems?
What are the intentions with providing costumers these systems?	What kind of analysis do you do on the data?
Is these systems in use, and at what percentage of the population?	Do you find the process of analysing this data cumbersome?

Table 2.2: Interview questions that can be found in the interview guide, **see attachment 14**

reasonable reach of the objectives. Follow up questions are to be made if deemed in the best interest of gathering relevant information. If the role of the interviewee is hard to define or the situation calls for it, a mix of the questions is allowed. The interviews are to be recorded employing topic-specific keywords that after the interview are to be transcribed for a fully presentable interview report immediately. The interview reports need to be approved by the interviewee before any use.

2.4 Data analysis/document study

The main purpose of the document study was to provide information regarding **Q1**. The only prerogative this research question puts forward is to identify parameters provided by the studied PM systems. This makes the document a pretty straightforward process once the necessary documentation has been acquired through the snowball sampling. The collection of documents to study proved difficult. Several attempts at acquiring data failed and any acquisition stage 1 data was not successful. Furthermore, there were initiated attempts at collecting data from the PM system VisionLink. The process was underway, but time constraint eliminated the option of pursuing this path any further. There was however discovered several similarities between VisionLink and the other two PM systems investigated. Due to the termination of a further investigation into VisionLink, there is not present any arguments based off of the preliminary findings of the investigation of VisionLink other than that these systems are comparable.

Limitations

There are some limitations when it comes to the kind of data that is available. Considering the scope is dealing with the investigation of commercially active parties, PM providers, it is fair to assume that Certain data might be considered valuable company assets. In other words, competition, which is the main driving factor for productivity, will compel many companies from sharing. The suggestion that information about the inner workings of these PM systems is considered company assets was ultimately not proven, but it is a fair assumption based on real indicators.

CHAPTER

THREE

LITERATURE REVIEW

To sufficiently answer any of the objectives, essential context and concepts need to be explored. The main purpose of this chapter is to introduce this through findings done in the literature study, pre-study and the pilot study.

3.1 Productivity

During the *pilot-study* several different definitions of productivity in AEC-projects were highlighted and elaborated on. This study does not require a complete taxonomy of formulations of productivity if that is even possible. However, the objectives do demand a brief introduction in order to specify the type of productivity that this study is concerned with.

Productivity is closely correlated with efficiency according to Thomas et al. (1990) "Efficiency focuses on the process of converting inputs into outputs. Productivity is one measure of efficiency." Note that efficiency is the measure of how well a project utilizes resources towards their goals, while effectiveness is the order in which the project/activity/task can meet its goals, which is an important distinction to make. Yi and Chan (2014) define productivity as three components:

1. Power of being productive is the force behind production itself
2. Efficiency is a measure of how well the factors are utilized
3. Rate is a measure of the output of the factors of production over a defined period of time

This definition brings several dimensions to the term productivity, *rate* being the typical sort of definition that is most commonly associated with productivity. OECD's definition of productivity is more straightforward and more suitable in most instances: "In its simplest terms productivity is the output produced by a unit of study as a proportion of the inputs required to produce it" (as cited in Loosemore (2014)). Translating this in terms of an equation:

$$\boxed{Productivity = \frac{Output}{input}} \tag{3.1}$$

General productivity

AEC-projects, as with almost all real-world processes, deal with more than one input. Formulations of productivity that consist of all input and outputs of a project or production unit are known as *total factor productivity*(TFP).

$$\boxed{TFP = \frac{Total\ output}{Labor + Materials + Equipment + Energy + Capital}} \tag{3.2}$$

Total factor productivity

This definition, however, is difficult to measure in construction due to the factors in the denominator and numerator exhibiting different units (Thomas et al., 1990; Jonsson, 1996). There is, however, a workaround by using monetary value, sometimes estimated, as the common unit:

$$\boxed{TFP = \frac{Monetary\ value\ of\ output}{Monetary\ value\ of\ input}} \tag{3.3}$$

Monetary total factor productivity

If estimated accurately TFP does well by measuring a project or unit of production upon completion, but it does not reflect or pinpoint any unproductive activities that may have been performed during the project or production process. This is primarily due to TFP not isolating against any influencing factors in its unaltered form **(see equation 3.3)**. In addition, even if any unproductive activities are identified by other means, any measure of its impact, for example, the relative importance index(RII), cannot realistically and reliably be quantified. When examining construction equipment productivity, TFP is further diminished in its usefulness due to it requiring several inputs which are based on estimated, uncertain and varying factors manifested by typical AEC-project conditions.

In an effort to estimate productivity, *key performance indicators*(KPIs) are often used (Jonsson, 1996), note that these measure productivity indirectly. Project managers might have some idea of complex and indirect correlations between specific factors in a project that indicates either good or bad productivity. The most commonly accepted performance indicators are those that can be physically measured by monetary value, units, or man-hours (Cox et al., 2003). Measuring productivity in the case of loading operations with excavators does simplify the formulation of productivity. A definition similar to **equation 3.1** with a single denominator and numerator will provide sufficient information in the context of this study. Productivity measures with a single chosen denominator and numerator are called *single factor productivity*(SFP). One such SFP is *Construction labour productivity*(CLP). The CLP measure is concerned with the productivity of the labor force, and it is however easily translated to earthmoving operations**(see table 3.4)**. Note the variables in this factor are indeed subject to different definitions depending on the purpose of the measurement**(see section 3.2)**.

$$\boxed{CMP = \frac{Volume\ \ or\ \ mass}{Time}} \tag{3.4}$$

Construction machine productivity

One might also be interested in measuring different combinations of the denominators to produce the desired factor which is called a *multifactor productivity*(MFP). The MFP measure of productivity is essential to the study since if one were the substitute the input of time in **equation 3.4** with for instance loading costs, the input is no longer a singular factor and measure must be categorized as either MFP or TFP depending on how strict one is when defining the terms.

Level of measurement

Section **3.1** explored some of the basics in general productivity. The different measures all have strengths, weaknesses, and purpose. They can all be applied to every *level of measurement*(LOM). For instance, if a TFP measure were to be applied to the site level, it would only measure the productivity of the contractor on site. There can be attributed some ambiguity here since site activities do not only consist of contractor activities, but that is not of relevance to the study other than to define the concepts adequately. Note that even though the productivity of the project in its entirety is not measured in this instance, it does indicate that the overall productivity of the project is healthy. Since the topic of this thesis revolves around construction equipment, specifically excavators, the LOM of this study will be solely concerned with measurements at activity-level **(See figure3.1)**. **Nevn progression verification vs productivity improvement** lit24 Lit22 design coupled with measurement

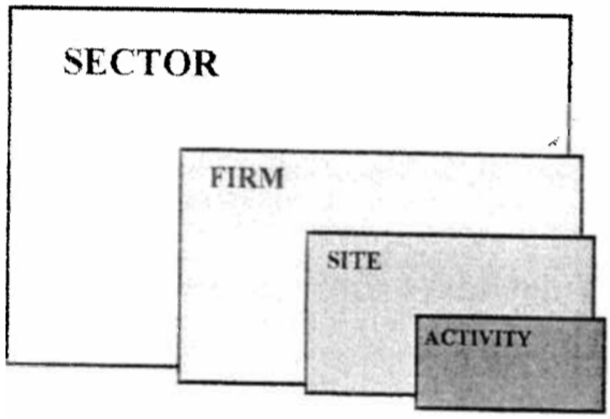


Figure 3.1: Level of measurement in construction, Jonsson (1996)

3.2 Rock quarrying

The formulas and methods of calculating the loading costs will not be presented, but which factor that is necessary to collect through ADC will be examined. Section 3.1 presented general and somewhat ideal formulations of productivity. Specific project activities such as excavator earthmoving operations present several obstacles for accurate measurements. If ADC systems are to be evaluated regarding its ability to measure productivity, a baseline for productivity measurement on excavator operations needs to be established. Vegard Olsen's PhD thesis (2009) and Odd Johannessen's (1992) report on operational control of construction machinery will be used as the main point of reference when establishing this. Note that these studies are not state-of-the-art research, but rather instructional studies in understanding fundamental principles of earthmoving productivity. When describing these fundamental principles the term *conventional* calculations/methods will be used. Choosing relevant material from these studies and presenting them here have two purposes, firstly it will provide a basis for answering **O2** and secondly it will bring context to the benefits ADC systems.

Earthmoving operations the term for productivity is sometimes referred to as capacity. This distinction can be attributed to the fact that the calculations using the term capacity is concerned with theoretical productivity, while productivity represents actual performed measurements Olsen, V. (2009); Johannessen, O. (1992). The conventional methods of calculating productivity on excavators consists of three essential steps(Olsen, V., 2009):

- Net cycle times
- Bucket size
- Fixed times

These steps consist of different measurements of time, as well as assumptions regarding the type, quantity, and state of mass within the bucket. Note that the essential steps listed above, provide the factors necessary for calculating *ideal* CMP **(see equation 3.4)**. The basic principles of these topics will be explored in the following section.

Volume and mass

Both volume and mass are metrics which are of interest to the scope. Both could be used as output, the volume being the norm in AEC-projects. In conventional calculations, the volume of the bucket in combination with state of mass and type of mass is used to determine volume per loading cycle. State of mass is particularly important due to it changing state, somewhat continuously, several times throughout the process of loading and transport. Both Vegard Olsen's PhD thesis (2009) and Odd Johannessen's (1992) report on operational control of construction machinery categorise the states of mass into three different states**(see table 3.1)**: *Solid state* - undisturbed natural state of mass; *Loose state* - disturbed and variable state from loading to unloading; *Placed state* - mass at rest after transport and possibly processing.

State of mass	Designed	Executed
Solid	dsm^3	esm^3
Loose	-	elm^3
Placed	dpm^3	epm^3

Table 3.1: State of measurement of mass, table 5.1 (Johannessen, O., 1992)

Once the volume of a certain mass is measured at different states, volume ratios can be calculated by using the formulas in **Table 3.2**.

Denotation	Description	Formula
k_{v1}	Ratio from executed solid state to executed loose state:(expansion)	$\frac{elm^3}{esm^3}$
k_{v2}	Ratio from executed loose state to executed placed state (compaction)	$\frac{epm^3}{elm^3}$
k_{v3}	Ratio from executed solid state to executed placed state(expansion + compaction)	$\frac{epm^3}{esm^3}$ or $k_{v1} \times k_{v2}$
k_{fo1}	Surplus ratio at breakout from solid state (ratio between designed and executed)	$\frac{esm^3}{dsm^3}$
k_{fo2}	Surplus ratio at placed state (ratio between designed and executed	$\frac{epm^3}{dpm^3}$

Table 3.2: Formulas for volume transition ratios, formula 5.1-5-.5 (Johannessen, O., 1992)

Table 3.3 presents empirical data of typical volumes ratios for the most common types of mass encountered in earthmoving. These ratios have several uncertainties, the level of moisture, equipment, method of excavation, operator experience etc.

Type of mass	esm^3	$elm^3(k_{v1})$	$epm^3(k_{v2})$
Rock	1.0	$1.5 - 1.65$	$1.35 - 1.5$
Moraine	1.0	$1.3 - 1.4$	$1.0 - 1.1$
Gravel	1.0	$1.1 - 1.2$	1.0
Clay	1.0	$1.3 - 1.4$	$1.0 - 1.2$

Table 3.3: Typical volume ratios: table 5.2 (Johannessen, O., 1992), Table D.2 (Olsen, V., 2009)

Quantity of mass

The quantity of mass during one loading cycle is determined by what bucket the excavator has attached. The range of buckets suitable for a particular excavator is determined by *original equipment manufacturer*(OEM) specifications of the machine in question. The bucket size, or volume of the bucket is constant, however the *bucket fill factor* is uncertain. The bucket fill factor is an estimation where *Good* equals 90%; *Medium* equals 85% and *Poor* equals 80%.

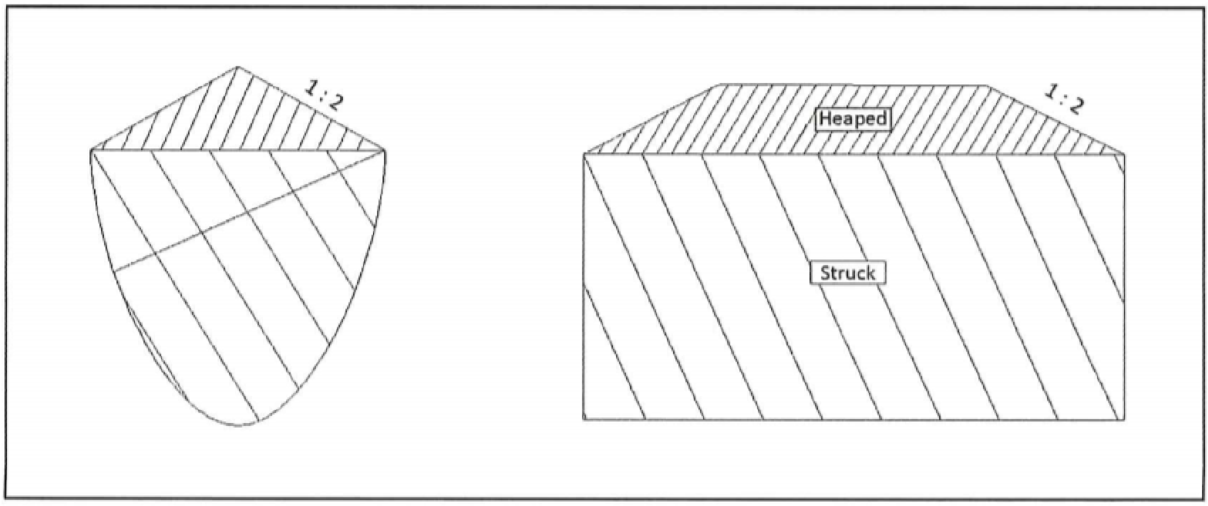


Figure 3.2: Illustration of bucket fill, SAE rated(Society of Automotive Engineers, figure 3.1 Olsen, V. (2009)

Loading conditions	Bucket fill factor
Good	90%
Medium	85%
Poor	80%

Table 3.4: Bucket fill factors for backhoe excavators, Table 3.3 (Olsen, V., 2009)

Measurements of time

There are several different measurements of time which relates to earthmoving operations and excavator operations. The more distinct and explicit these can be defined, the more accurate the calculation becomes.

Cycle time

Different construction equipment require different definitions of cycle times. The excavator cycle time consists of four main sub-activities(**see table 3.4 and figure 3.3**).

These sub-activities when combined constitute the ideal net cycle time. However, a loading cycle is in most cases never ideal. The net cycle time can be compared to the term in wrench time (Yi & Chan, 2014), which is the definitions of time spent doing strictly productive work towards the output. However such measurements of time are unrealistic since there is in almost all activities prerequisites to performing that activity. In earthwork operations, these prerequisites are defined as *Fixed time*.

Sub-activity	Description
Filling the bucket	The time from when the machine touches the rock pile, fills the bucket and until it starts swinging towards the truck.
Swinging to the truck	The time from when the machine starts swinging away from the pile until the rock starts falling from the bucket.
Dumping the bucket	The time from when the rocks start falling from the bucket until the bucket starts swinging away from the truck.
Swinging to the pile	The time from when the bucket starts swinging away from the truck until the bucket touches the rock pile.

Table 3.5: Excavator net cycle time, Olsen, V. (2009), page 63.

Figure 3.3: CAT 390F loading a dumptruck, Tvedestrand-Arendal forbindelsen - AF Gruppen AS

Fixed time

Performing a loading cycle is accompanied by certain sub-activities which are necessary for the cycle to be completed. As mentioned these prerequisites are called fixed times **(see table 3.5)**. Explicitly defining fixed time becomes evidently important when realizing it is one of the required steps when calculating CMP.

Gross time

Combining net cycle time and fixed time grants *gross time*. There is, however, a measurement of time that is outside the ones identified already, and that is *Loss of time*. Loss of time consists of all kinds of time loss that are due to unproductive use of time. Time that can be categorised as loss of time is in most cases a result of unpredictable circumstances: *Variable repairs*; *personal delays*; *blasting delays*; and *other incidental loss of time*. Somewhat less intuitive are certain delays attributed to lost time that is considered necessary for normal function of the excavator and its continuous operation (Olsen, V., 2009).

Sub-activity	Description
Truck maneuver	The time from when the loading machine is ready with the bucket lifted until the truck is standing still under the bucket.
Trimming of the rock pile	The time for trimming the rock pile. To get a representative trimming time, an adequate number of trucks is required.
Picking out large boulders	The time needed for picking out boulders that are too large for the truck of the primary crusher. Includes the time for loosening the rock from the pile and putting it aside.
Smoothing the working plane	The time for smoothing and preparation of the working plane when this is necessary. The operation includes cleaning of rock dropped on the plane during loading and leveling the rough surface to get efficient loading.
Moving during loading	the time for the loader to do necessary moving during loading.
Preparation of working plane	The time for preparing the work plane in the rock pile. The working plane is continuously prepared as the loading progresses through the rock pile. The time may be difficult to observe in short time studies.
Block breaking	The time for breaking oversized blocks by a cast steel ball. The time expresses the time picking the steel ball and dropping it on the block. Sometimes the block is dropped on the steel ball, which is lying on the bench floor.

Table 3.6: Excavator fixed time, Olsen, V. (2009), page 63-64.

Loading conditions	Truck manoeuvre	Trimming of pile	Smoothing of working plane	Picking out boulders	Moving during loading	Total fixed time
Good	0.25	0.05	0.10	0.00	0.25	0.65
Medium	0.25	0.15	0.10	0.05	0.25	0.80
Poor	0.25	0.25	0.10	0.15	0.25	1.00

Table 3.7: Normalized fixed times per truck load for backhoe excavators, Table 3.4 (Olsen, V., 2009)

Loss of time that can be considered necessary is: *scheduled maintenance* and *refuel*.

Effective hours

The measurements of time presented are essential in determining excavator productivity. *Effective hours*(eh) is also one of the key parameters when calculating excavator productivity. There are differing definitions of what effective hours are, however in the context of this study it is to be defined as the number of hours of a shift that can be attributed to *gross time*. This means that if an excavator operator shift consists entirely of loading operations, the gap between shift hours and effective hours is entirely *loss of time*.

3.3 Loading costs

applying monetary value as input when calculating CMP produces a MFP measure that is of value in several estimation processes including tendering. Acquiring monetary input value of excavator loading operations requires several factors. Olsen (2009) states the following factors as essential when estimating loading costs:

- Loading capacity
- Economic life of loading machines
- Tyre life
- Prices of equipment, fuel and labour

Tyre life is not relevant, since only crawler excavators are being considered. Price of equipment, fuel and labour are case specifics which is not important since these are always available when performing the calculation. Accurate Fuel consumption, actual work hours, and different aspects of equipment status is valuable to collect, not only to provide a database of empirical data for future needs, but also for progression control and overall performance monitoring. Loading capacity, or loading productivity **(see section ROCK QUARRYING)**, which provides the CMP measure, is a precursor to calculating loading costs.

3.4 Summary of rock quarrying

The examination of material from the pilot-study and the pre-study revealed several important aspects and factors that need to be collected by ADC system in order to provide adequate productivity measures. A SFP measure defined as CMP **(see equation 3.4)**, will be the benchmark for what is needed of data when doing productivity measurements. The essential context and needed parameters for calculating CMP is described in sufficient detail in **3.2**. A MFP measure of productivity using monetary inputs, excavator loading costs, was also identified as a point of interest in the context of this study. The specifics and details of the equations behind the loading costs are not presented here. The parameters that are needed to calculate this MFP measure was however analyzed **(see table 3.8)**.

Parameter	Description
eh	Effective hours during a shift or loading session.
h	Total quantity of hours spent performing loading.
fc	Fuel consumption.
Net cycle time	Ideal cycle time, 3.5 P
Fixed time	time spent doing essential sub-activities that are prerequisites to net cycle time 3.6
Loss of time	All time spent doing nonproductive activities. See section 3.2
Quantity of mass	DO IT

Table 3.8: Parameters identified as essential to acquire through ADC in order to calculate excavator loading productivity.

3.5 Project performance control

Navon & Sacks (2007) presented an overall model, *Automated project performance control* (APPC), which autonomously collects and assesses data from construction activities **(See 3.4)**. This model is a good visual tool for understanding the purpose and context of ADC systems in AEC-projects. Note that such a system is compatible with other major concepts being researched in the industry. If done correctly, a *building information model*(BIM) would arguably further the automation process of APPC systems since all the design information is retrievable from one source, making the update and comparison process automatic. This topic will not receive further elaboration other than pointing out that exploring ADC systems tailored for different activities is only part of a bigger research project.

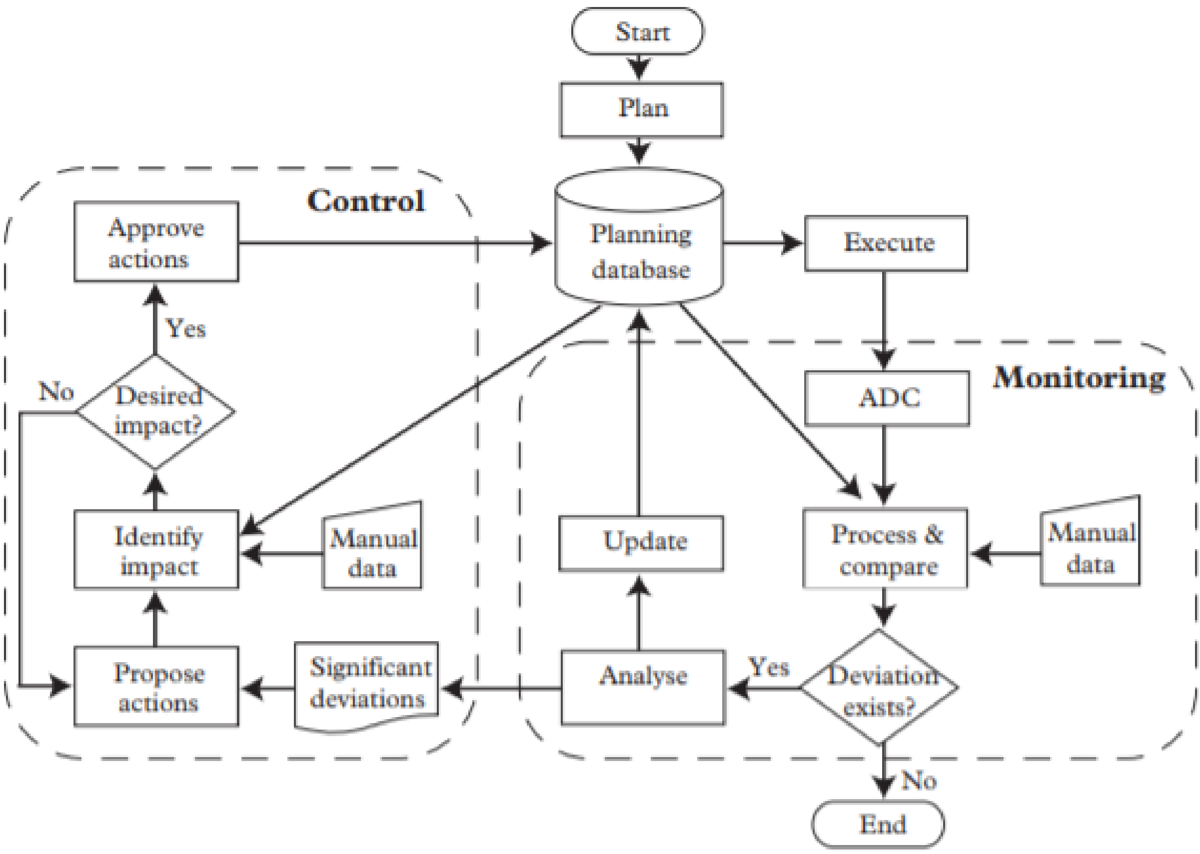


Figure 3.4: Automated project performance control(APPC), Navon & Sacks (2007)

3.6 Automated data collection

ADC is the process of autonomously acquiring specific parameters from activities (Navon, 2007). Each activity exhibit different characteristics which necessitates a tailored system for each activity that is to be monitored. If an AEC-project is to be monitored as a whole, there needs to be several ADC systems in place, measuring the KPIs, productivity measure, and PIs. Each ADC system consists of a control cycle which compares the collected data to design data **(see 3.5)**.

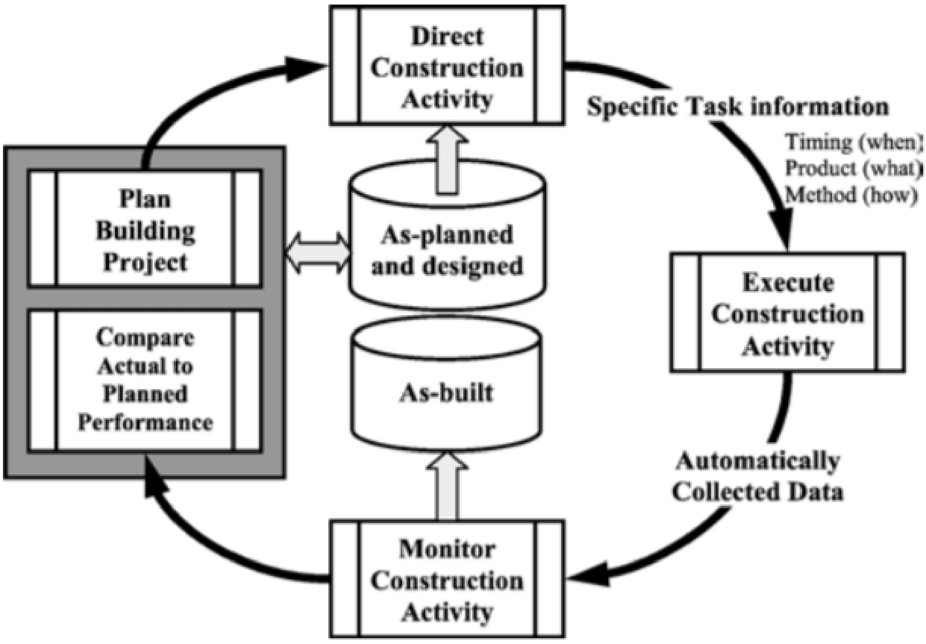


Figure 3.5: Typical control cycle for an AEC-project with ADC implementation, Navon & Sacks (2007)

The crucial characteristics, as initially identified**(see section1.1)**, of an ADC system is that it collects data automatically, in RT or NRT, accurately and that the system is robust and cheap. This was part of the initial justifications for initiating this study.

Characteristic	Description
Automatic	The system needs to collect the data automatically.
Robustness	The system needs function reliably on a specific activity.
Economical	The ADC system needs to be affordable for the party in charge of performing this activity. Note that this party often might be disincentivized to project productivity(such as sub-contractors).
Accuracy	The system needs to provide equal or greater accuracy than manual measurements.
Near real-time	It is of importance that the system collects the data in close to real-time.

Table 3.9: Essential characteristics of a functional ADC system as identified in **section1.1**

Firstly, if any ADC system is to be applied, its capability to collect the data that is of interest is the first criteria. One could argue this a trivial criterion, but, as will be shown(**see section 3.6**, current commercialized systems often don't share the purpose of productivity monitoring. The automated characteristic dictates that the system must collect data with close to none human interaction. Although mentioned in scope limitations **(see section 1.3)** this characteristic is not to be confused with an autonomous system. Hard automation, such as an autonomous system, is to some extent disconnected from any human actions in order to function and is not what is meant by the system being automatic. An autonomous system is adaptive to deviation from standard routine, while an automatic system has a set of predetermined operations. Setup, maintenance, corrective actions and follow-up is considered a natural part of an ADC system in this study. Robustness captures the systems ability to deal with unpredictable scenarios and other variations that may affect the systems capability to produce the anticipated data. Robustness is in this context a result of how well thought out the predetermined operations of the system are. The fact that the scope is only concerned with construction excavator loading activities does significantly lower the possibilities of deviation. Although some systems are quite demanding financially, the primary challenge is making such systems standard for every proprietor of a construction equipment fleet. This topic will not receive further examination other than mentioning that the conditions of AEC-projects are known for blurring some incentives. Since the initial financial input is coupled with other factors, the economic characteristic is abnormally essential. The initial financial input of implementing such a system needs to be sufficiently tolerable for it to be beneficial in the eyes of the party required to implement it.

Accuracy is central to any productivity measurement, and there are several strategies for increasing this characteristic. Most such strategies are concerned with filtering and altering the data in order to increase its accuracy. This study is not concerned with such strategies, but rather the qualitative properties of a raw data measurement.

In construction, RT is defined as equal or greater than 1 Hz data update rate(as cited in Pradhananga & Teizer (2013)). An update rate this excessive is in most instances not needed and is disposed to a considerable increase in cost. Corrective action can be made in near-real-time(NRT) and is arguably sufficient in the context of ADC systems. What constitutes NRT is hard to define, due to it being dependent on what is being measured. However, *"within minutes"* would be sufficient in almost every scenario connected to earthmoving operations with excavators.

Argument	Source
The current practice is labor intensive because; it relies on manual data collection; it requires extensive data extraction from drawings, from plans and from databases as well as a lot of calculations.	Navon (2007), Gong (2011), Louis & Dunston (2017), Azar et al. (2013), *Attachment 9*, *Attachment 12* and Memarzadeh et al. (2013)
The quality of manually collected and extracted data is low, it is error prone and expensive. Projects are, therefore, controlled infrequently and in generic terms, which makes analyzing the causes of deviations difficult.	Navon (2007)
A random interruption in the process containing several parallel sub-processes may cause largescale problems. These interruptions should be handled immediately and preferably automatically as fast as possible.	Viljamaa & Peltomaa (2014), Navon (2005)

Table 3.10: Identified reasoning behind the use of automated data collection.

Level of alteration

In order for data to be valuable to project managers, construction site managers and other parties of interest, it needs to be filtered and processed. Although this statement is an assumption, it is one based in reality. Sensors collecting data automatically produce large amounts of data, which in context of management, monitoring and project control is unproductive to analyze and perform calculations on manually. ADC system, therefore, need filters and processes that produce data that is easily comprehensible in the context of its purpose. This study is not concerned with specifying any details of how to filter or process any such system, but when discussing what kind of data is available today through ADC systems, a categorization of how the data is altered is needed:

- Stage 1, unaltered raw data produced by sensors.
- Stage 2, filtered and processed(noise, unwanted data in context to its purpose)
- Stage 3, Graphs, visualization, reports, other analysis

Activity modes

The different measurements of time **(see section 3.2)** requires NRT identification of activity modes in order to correctly assign the quantity of time spent in the different modes. Any system aimed at measuring productivity with accuracy is required to identify which activity mode the excavator is in and measure its duration in said activity mode.

3.7 Systems and strategies

Through the literature search and review of the chosen material, several different approaches to ADC systems were identified. These approaches differ mainly in what their purpose is, but there are also differences when it comes to what stage the data is in when presented to the user. A brief introduction to some of the strategies and systems that were identified.

Legacy engine systems

Present factory fresh excavators are delivered from the *original equipment manufacturers*(OEM) with a *legacy engine system*(LES) which registers data when the machine is operating. LES's main function is to provide operational functionality of the machine. There are also secondary functions such as providing data back to the OEM and the intermediary retailer. Such data is most commonly used in fleet control, empirical data for future equipment improvement and insurance cases (as cited by Qingyuan et al. (2017)). Any system that takes advantage of the LES in order to collect data is in this study to be known as *internal* systems. There are several difficulties connected to internal systems. First of all, the actual details of the LESs sensor accuracy and any data processing that is done is not available to the public. Secondly, there are site-specific constrictions to the suitability of internal systems due to the variation of OEMs in most construction equipment fleets(Mathur et al., 2015). Differing OEMs, as well as a wide range of models, is a compatibility issue (Ahn et al., 2015).

Performance monitoring systems

Performance monitoring(PM) systems monitor construction equipment performance mainly in terms of fuel consumption and health. Such systems are also known as *vehicle health monitoring systems*(VHMS) (Mathur et al., 2015; Azimi et al., 2011). These PM systems are provided by the OEM and take advantage of the LES and its *on-board dianostic*(OBD) system. VisionLink, CareTrack, ConSite and Connected Community are some of the most prominent PM systems in commercial use. At least partial access to these systems are part of the standard package when purchasing a new machine. There are subscription fees for some of these systems. Also, add-ons for additional data are available in some instances. PM systems provide the user with *stage 3* data.

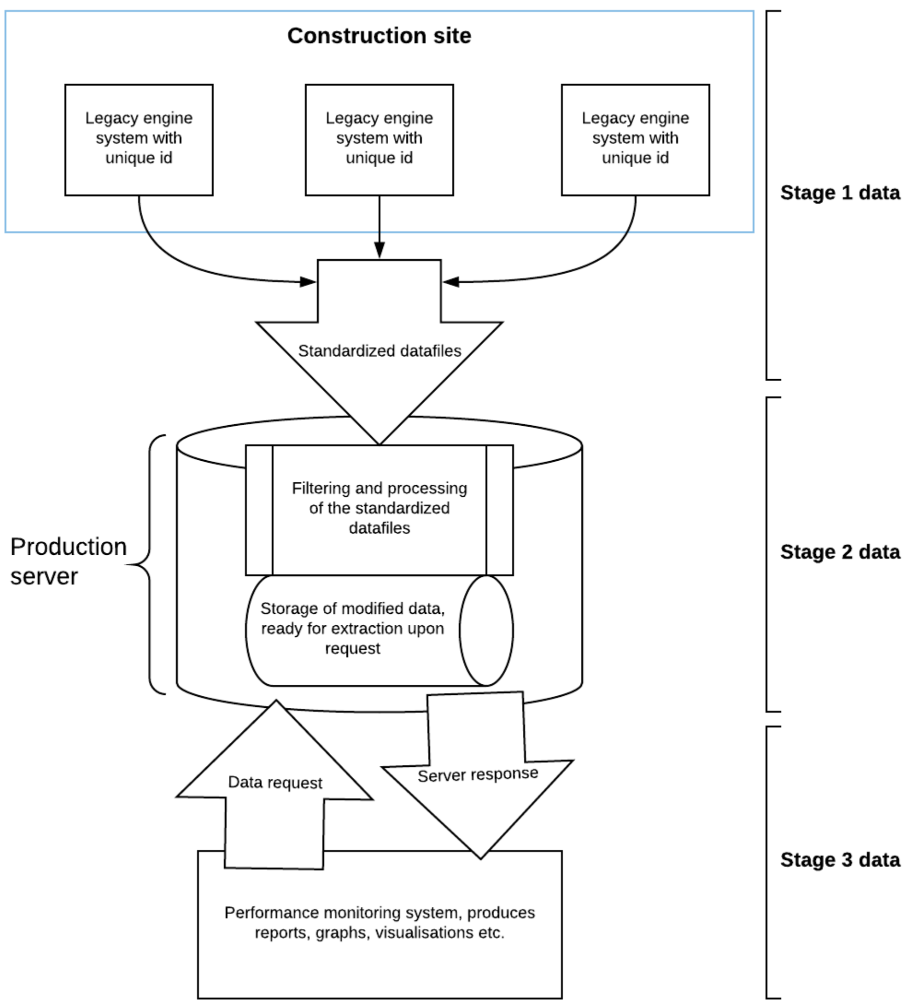


Figure 3.6: An overview of PM systems in principle, based off of correspondance with field experts Per Ola Berntsen and Stian Lund at Sitech Norway AS

External measurement systems

Although the scope is not explicitly concerned with these strategies, they were useful to investigate in short not only to inform the reader of the field of context of PM systems but also to highlight that such systems could be incorporated to PM systems in order External measurement systems take advantage of strategies which are separated from LES and any other systems that are part of OEM systems.

Machine control systems

Machine control(MC) systems are third-party systems which use *global navigation satellite systems*(GNSS) receivers to pinpoint the location of the equipment. Trimble, Topcon, Novatron, and Leica are some of the top global contenders for such systems. By accurately determining the equipment's coordinates on earth and combining it with spatial data from project design, a geospatial coordinate system can be established. This enables machine operators to perform operations in accordance with what is planned accurately.

MC systems require a receiver antenna installed on the equipment. Installing MC systems on an entire fleet of excavator present a considerable financial investment, which makes the system fair poorly in the economic sense. However, MC systems are quite common on sites due to it allows the operator to accurately perform the task that is required to complete the job. The MC systems use high-end GPS technology which provides accurate time-stamped spatial data. However, this is the only data such a system can provide(Azar et al., 2013). Note that such data can provide with cycle time measurement on earthwork equipment, but the excavator is not one of those. Although accurate, the spatiotemporal data MC systems can provide does not yield any specific factors related to activity modes.

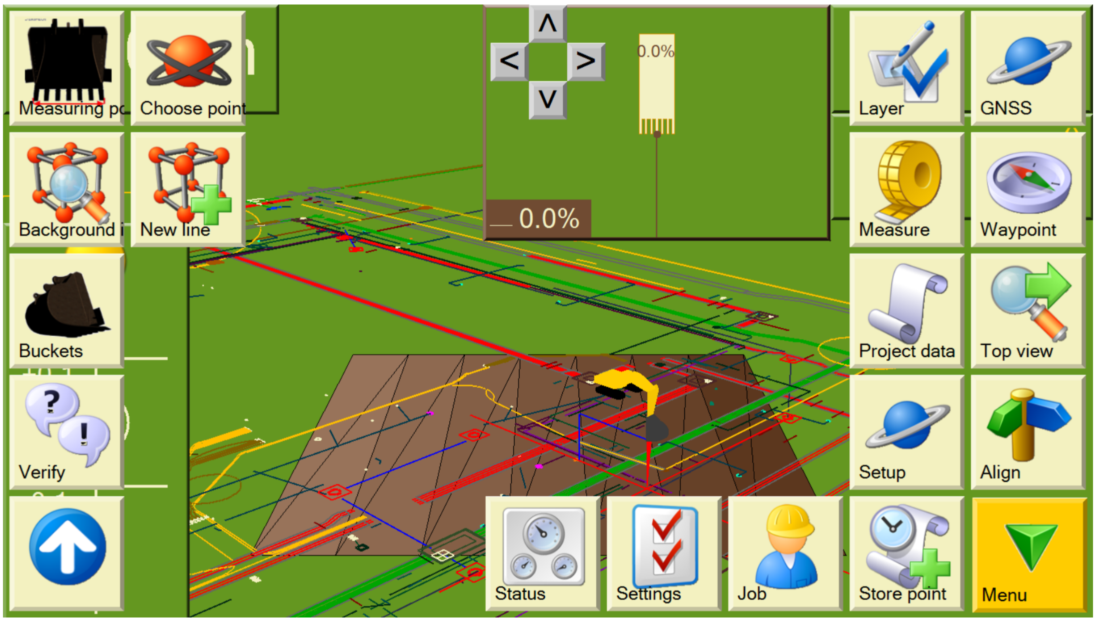


Figure 3.7: DigPilot demo software, MC system accessed by cooperation with Jan Floberg, CEO Gundersen & Løken AS

Bar code and RFID

Barcode and *Radio frequency identification*(RFID) have a considerable reputation for success in the field of productivity. The RFID strategy has been implemented with considerable success on earthmoving operations (Ibrahim & Moselhi, 2014), this was in the context tracking spatiotemporal data dump truck movement. The strategy of tagging material/equipment employing bar coding or RFID is however not a plausible strategy in the context of excavator loading operations (Navon & Isaac, 2014). Isolated, the limitations of these systems are obvious and require no further inquiry in order to determine its potential in the context of excavator loading operations. RFID could, however, be used in combination with other strategies if the strategy in question could not identify equipment identity (Yang et al., 2015; Azar et al., 2013; Navon & Sacks, 2007).

LADAR

Laser detection and ranging(LADAR) is an optical measurement strategy that involves emitting pulsating laser light and recording the variations in the reflected light in order to construct an image of the area measured. LADAR is most commonly used to make maps by scanning topological characteristics. There are several areas of application for such technology, and it has been used in construction to make 3D models of either terrain or structures. In the context of earthmoving operations, it has been found that LADAR can produce information such as object recognition, changes in terrain and terrain characteristics (Cheok & Stone, 2004).

Optical recognition systems

Optical recognition systems are concerned with, at least in the context of earthmoving operations, identifying and separating construction equipment from other optical noise(Gong, 2011; Memarzadeh et al., 2013). In some instances also identification of activity modes are presented(Azar et al., 2013; Yang et al., 2015). The data produced by optical systems does provide data about cycle times and activity modes but cannot produce any output parameters other than conventional ones.

Inertia recognition

There are several sensors which can be applied externally that takes advantage of the inertial forces acted upon the excavator while performing its loading operations. An accelerometer in its most primitive form measures what is known as *proper acceleration*, by means of registering vibration. In principle, proper acceleration refers to the fact that an accelerometer on earth is always affected by gravity. Accelerometers have been applied to measuring parameters connected to excavator productivity using *inertial measurement unit*(IMU) (Hyunsoo et al., 2018) and *microelectromechanical systems*(MEMS) (Ahn et al., 2015) with promising results. As with optical recognition systems, these sensors can register data about cycle times and activity modes but is not able to provide output data.

CHAPTER

FOUR

RESULTS

The following chapter presents all the major findings. These findings are a result of the document study and interviews in context of the theory presented due to the literature review.

4.1 What kind of data is collected by PM systems

A total of four documents was studied in an attempt to determine which data is registered by PM systems. Nasta AS provided a monthly fuel report from the PM system ConSite^{TM} **(see attachment 17)**. Parameters identified from this document are presented in **table 4.1**. Volvo AS provided one weekly fuel report and one monthly report from AF Gruppen's project *Tvedestrand-Arendal forbindelsen* which is a large road project involving removing and transporting seven million cubic meters of earth and stone **(see attachment 15 and 16)**. The parameters extracted from these reports are presented, unaltered, in **table 4.2**. Volvo AS also provided a *"dummy"* datasheet, with actual parameters but no real data, produced by the production server of the CareTrack^{TM} system**(see attachment 18)**, these are presented in **table 4.3**.

Parameters

The parameters presented in the following tables are all either stage 3 data or stage 2 data **(see figure 3.6)**. Furthermore, the different sources exhibit differences in the definitions of the parameters. Some of the parameters are also compound parameters, which means that they are calculated from two or more of the other parameters.

Parameters(unit)	Comment
Engine operation hours(h)	Timestamped, Stage 3 data
Actual operation hours(h)	Timestamped, Stage 3 data
Non-operation hours(h)	Timestamped, Stage 3 data
Front operatio n hours(h)	Timestamped, Stage 3 data
Swing operation hours (h)	Timestamped, Stage 3 data
Travel operation hours, fast mode and slow mode(h)	Timestamped, Stage 3 data
Attachment operation hours(h)	Timestamped, Stage 3 data
Coolant temperature(Deg.c)	Timestamped, Stage 3 data
Hydraulic oil temperature(Deg.c)	Timestamped, Stage 3 data
Utilisation(%)	Timestamped, Stage 3 data
Fuel consumption(L)	Timestamped, Stage 3 data
Fuel efficiency(L/h)	Compound parameters, timestamped, Stage 3 data
Oil pressure(Scale)	Timestamped and activity-stamped, Stage 3 data

Table 4.1: Identified parameters by document study of **Attachment 17**

The parameters presented in **table 4.1** are all stage 3 data. They are all presented graphs and other visual methods, most of them on a timeline which indicates that the measurements are timestamped **(see figure 4.1)**.

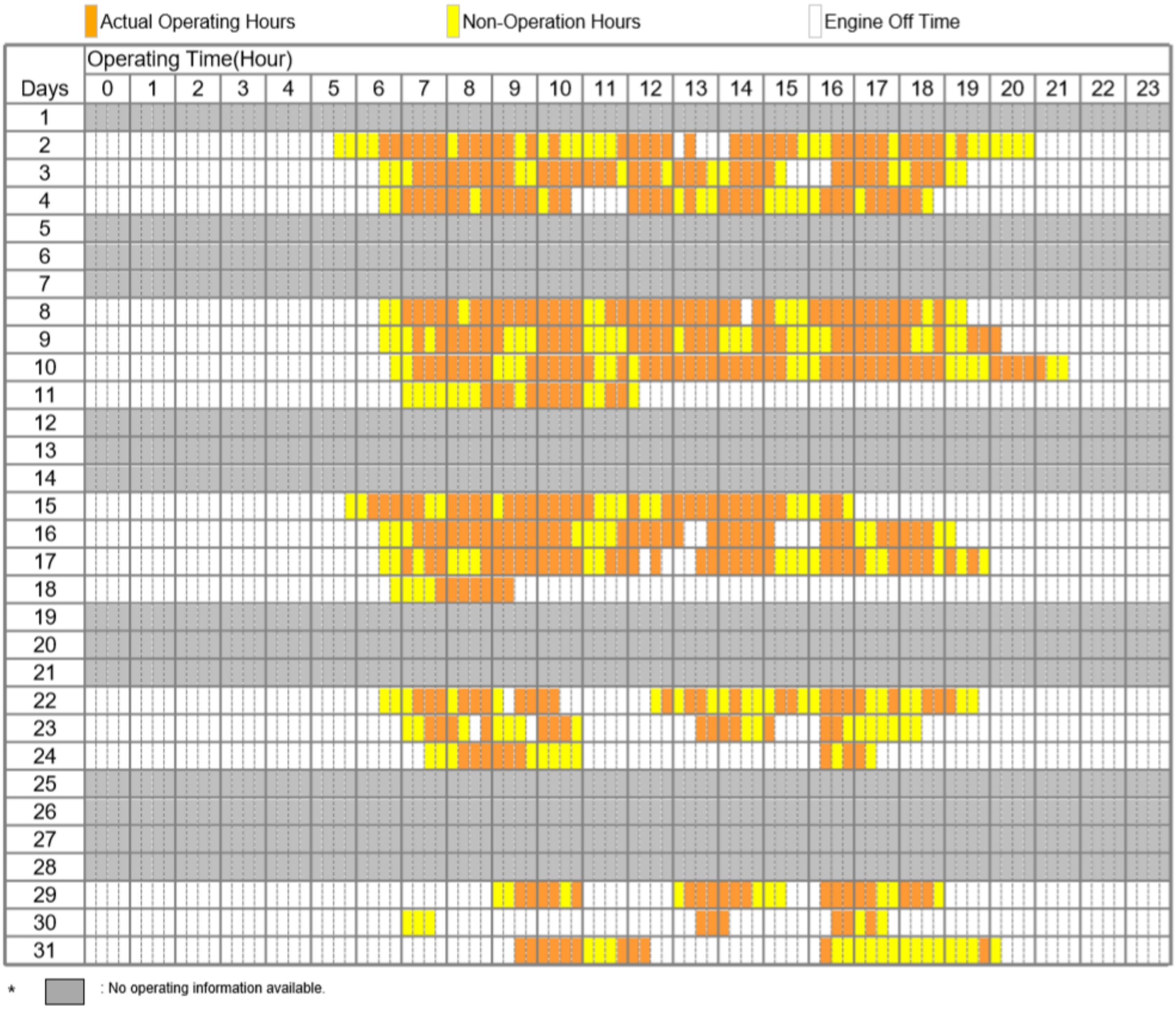
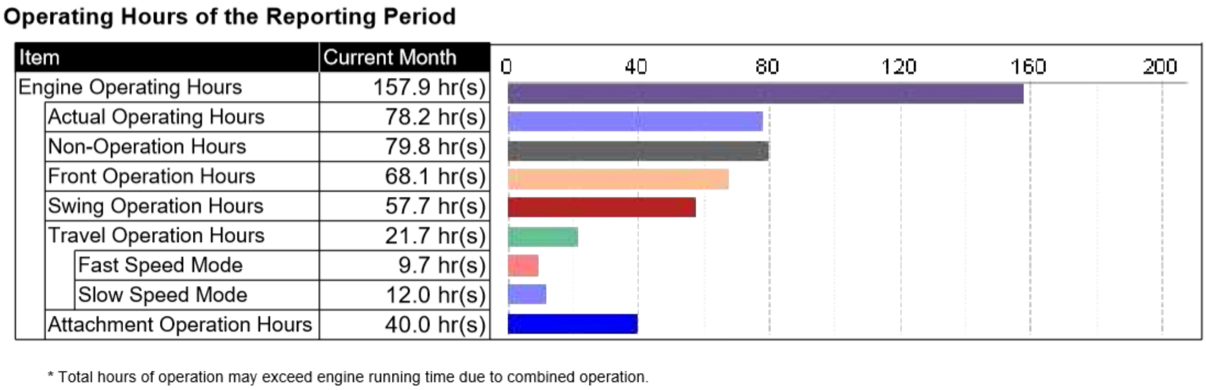


Figure 4.1: Operating hours categorized by a selection of activity modes, **Attachment 17**

Figure 4.1 indicates that the interval of measurement is every fifteen minutes or less. Furthermore, the document shows that ConSite does distinguish activity modes **(see figure 4.2)**.



Item	Current Month
Engine Operating Hours	157.9 hr(s)
Actual Operating Hours	78.2 hr(s)
Non-Operation Hours	79.8 hr(s)
Front Operation Hours	68.1 hr(s)
Swing Operation Hours	57.7 hr(s)
Travel Operation Hours	21.7 hr(s)
Fast Speed Mode	9.7 hr(s)
Slow Speed Mode	12.0 hr(s)
Attachment Operation Hours	40.0 hr(s)

Figure 4.2: Operating hours categorized by activity modes, **Attachment 17**

Parameters(unit)	Comment
Total fuel consumption(L)	Timestamped, Stage 3 data
Total hours(h)	Timestamped, Stage 3 data
Work fuel consumption(L)	Timestamped, Stage 3 data
Fuel consumption per hour(L/h)	Timestamped, Stage 3 data
Utilisation(%)	Timestamped, Stage 3 data
Wait(h)	(<5min), Timestamped, Stage 3 data
Excessive idle(h)	(>5min), Timestamped, Stage 3 data
CO2(Kg)	Timestamped, Stage 3 data
Objective performance	Factor comparisons with industry averages, Stage 3 data

Table 4.2: Identified parameters by document study of **Attachment 15 and 16**

The parameters and visualization present in **attachment 15 and 16** have substantial fleet optimisation opportunities **(see figure 4.4)**.

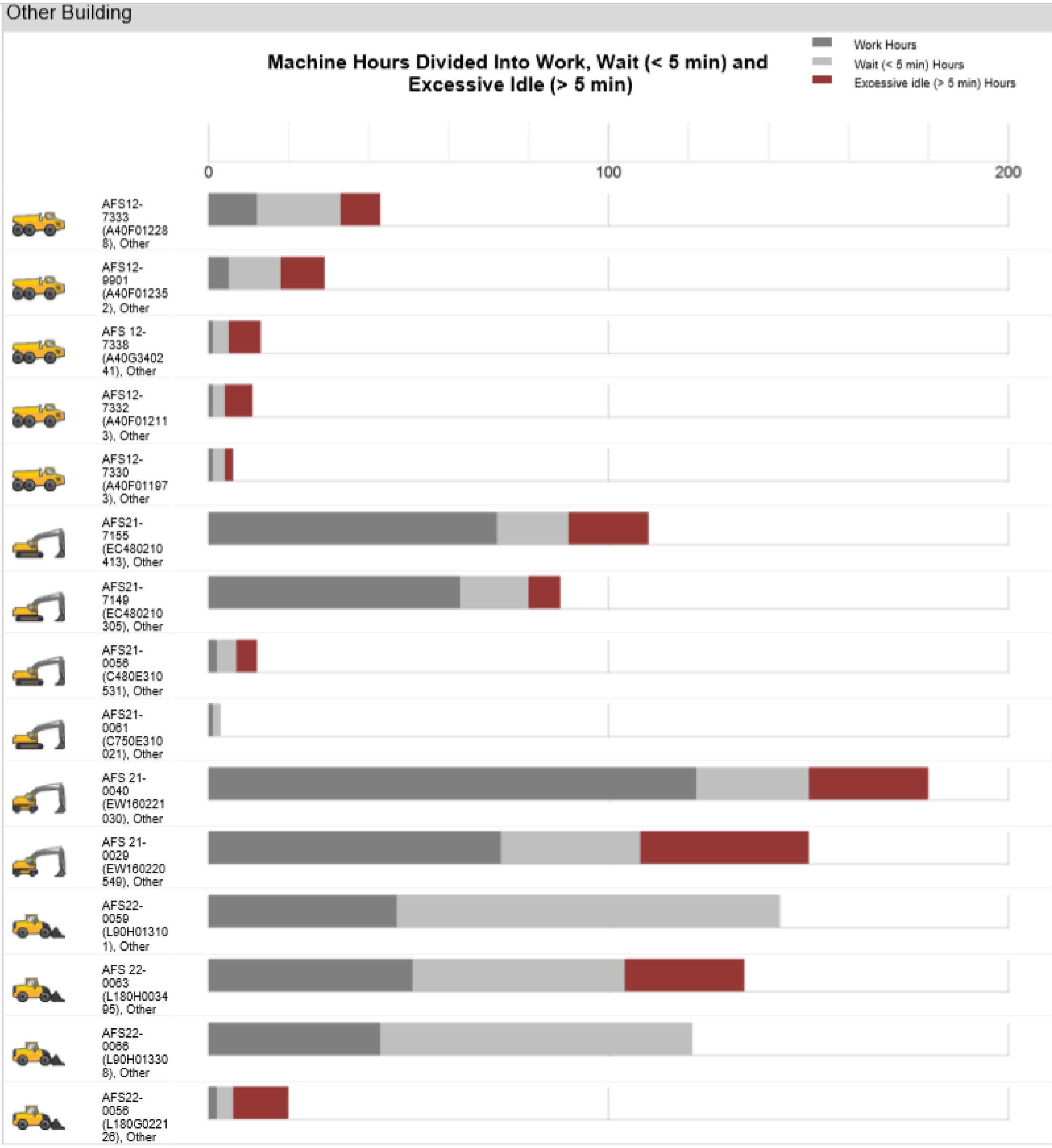


Figure 4.3: Operating hours of fleet categorized by activity modes, **Attachment 16**

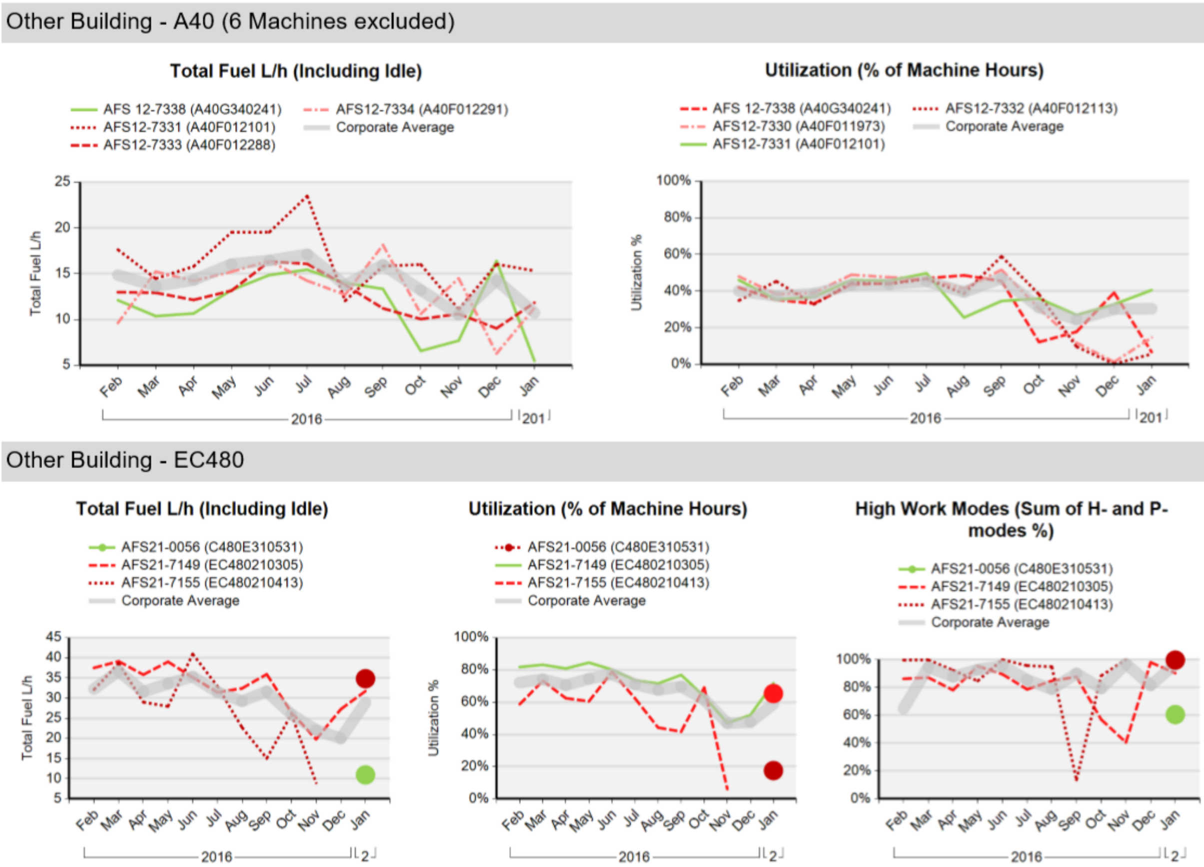


Figure 4.4: Some key parameters of fleet visualized, **Attachment 16**

Parameters(unit)	Comment
Total Life hours(h)	Stage 2 data
Machine hours(h)	Stage 2 data
Utilisation(%)	Stage 2 data
Idle(%)	(wait<5min +excessive idle >5min)
Wait(%)	(<5min), Stage 2 data
Excessive Idle(%)	(>5min), Stage 2 data
Work hours(h)	Stage 2 data
Wait(h)	Stage 2 data
Excessive Idle(h)	(>5min), Stage 2 data
Average speed work(Km/h)	Stage 2 data
Overall fuel efficiency(l/h)	(Idle included), Stage 2 data
Fuel efficiency work(l/h)	(Idle included), Stage 2 data
Fuel efficiency total idle(l/h)	Stage 2 data
Fuel total(l)	Stage 2 data
Fuel work(l)	Stage 2 data
Fuel idle(l)	Stage 2 data
Fuel wait(l)	Stage 2 data
Fuel excessive idle(l)	
Average payload utilisation(%)	Stage 2 data
Overload occasions (#)	Stage 2 data
Fuel efficiency(l/h) F-mode	Stage 2 data
Fuel efficiency(l/h) G-mode	Stage 2 data
Fuel efficiency(l/h) H-mode	Stage 2 data
Fuel efficiency(l/h) P-mode	Stage 2 data
Fuel efficiency(l/h) G-mode	Stage 2 data
Fuel all modes(l)	Stage 2 data
Hours all modes(h)	Stage 2 data
Fuel efficiency distribution all modes(%)	Stage 2 data
Fuel total/score	Stage 2 data
Utilisation score(%)	Stage 2 data
CO2 actual(Kg)	Stage 2 data
Production(kg)	Stage 2 data
Efficiency(kg/h)	Stage 2 data
Efficiency work(kg/h)	Stage 2 data
Efficiency (Kg/l)	Stage 2 data
Efficiency work(kg/l)	Stage 2 data
cycles(#)	Stage 2 data
cycles(#/min)	Stage 2 data
Average cycle time(min)	Stage 2 data
Average cycle distance(km)	Stage 2 data

Table 4.3: Identified parameters by document study of **Attachment 18**

The fuel report history **(see attachment 18)** provides a considerable amount of parameters. However, they are not explicitly accompanied by any timestamps other than what month the data in question was gathered. Also many of the parameters such as *production* and *cycles*, are not available on excavators **(see attachment 8)**.

4.2 Does the collected data provide sufficient information i regards to calculating productivity

As briefly elaborated on in **Chapter 1**, whether or not the registered data is sufficient is dependant on two dimensions. The first being that the parameters needed to calculate CMP are present in the data collected by PM systems. The second dimension is that the parameters within the collected data exhibit the required characteristics of ADC systems.

Required parameters

The literature review identified the essential parameters that are needed for in order to calculate excavator CMP **see table 3.8**.

Required parameters	Represented?	Comment
Effective hours	Yes	Present in all studied documents
hours	Yes	Present in all studied documents
Fuel consumption	Yes	Present in all studied documents
Net cycle time	Yes/no	Partially represented
Fixed time	Yes/no	Partially represented
Loss of time	Yes/no	Partially represented
Quantity of mass	No	Not directly available in any of the studied documents

Table 4.4: Comparison of required parameters vs parameters represented in the studied documents

Required characteristics

Required parameters	Represented?	Comment
Automatic	Yes	The data is collected automatically
NRT	No	The data is not accessible to the user other than weekly reports(Some parameters are available online)
Economy	Yes	PM systems can certainly be considered economical
Accuracy	Unknown	third stage data and no user access to how the stage one data is acquired is available.
Robustness	Unknown	Log of deviations not accessible to user

Table 4.5: Comparison of required characteristics vs characteristics represented in the studied documents

4.3 How is the data collected and being used today

The two categories of interviewees were *Field experts and system providers* and *Contractor and project Management* (see attachment 14). Four interviews were conducted in the first category and three in the latter.

Contractor data collection

When asked, contractor and project management reported subscription to parameters such as fuel consumption, CO2 quantity, volume of mass, work hours, and idle times **(see attachment 13, 12 and 9)**. These parameters were however collected from different sources within the same organization.

OK Entreprenør AS collected work hours through SmartDok^{TM}, fuel consumption and idle times through VisionLink^{TM} and lastly that the volume excavated was calculated through their MCS **(see attachment 12)**. Progression control was conducted by calculating the current excavated volume and comparing it to designed values. OK Entreprenør AS reported the use of TopoCad^{TM} to design their projects, only later exporting the file to Business Center^{TM} where the file could be sent out to the construction equipment. It was pointed out that project design from BIM usually did not have geospatial data which made the process of using this design data exceptionally cumbersome. The main problem with PM systems was claimed to be compatibility issues.

AF Gruppen AS revealed that the main bulk of data they collect is through the use of a *"modified"* version of SmartDok^{TM} **(see attachment 13)**. Operators manually enter the location of loading, equipment ID and type of mass being loaded. The operator also manually log every loaded truck. This information would then be used in an Excel^{TM} sheet to monitor where mass was gathered, where it was dumped along with the type of mass and equipment and operator ID. Productivity was calculated from truck specifications of capacity and number of loads, adjusted from experience. The excavator productivity is extrapolated from this. The main issue with using PM systems for a full analysis is the compatibility issues. The compatibility issues come from differing EOMs, age of equipment(either outdated software/hardware of none at all). Simply put too many differences and incompatibilities to justify the effort of applying them.

Oppland Maskinkompani AS was interviewed in the context of MCS DigPilot^{TM} and described that their data collection efforts as consisting of gathering progress control parameters, cost estimates, resource usage in order to produce key indicators for future reference **(see attachment 9)**. Oppdal Maskinkompani AS also reported that these data were gathered by using the work hour software SmartDok^{TM} to gather input data and DigPilot^{TM} to estimate output. Oppdal Maskinkompani AS reported that the use of MCS provided benefits such as resource savings regarding management; increased precision; reduced margin and requirement of error.

Field experts and system providers on the capabilities of PM system

Volvo AS reported that the CareTrack^{TM} system is capable of acquiring parameters such as map and coordinates, total hours, idle hours, waiting hours, mileage, fuel consumption, engine RPM and cycle times. Map, coordinates, fuel consumption and fuel level are available in NRT online. The remaining parameters are sent as a data package every 24 hours from the production server to the CareTrack^{TM} server where weekly and monthly reports are made available to clients. The cycle times are only available for articulated dump trucks. The interview also revealed that the common reason for customers to acquire PM systems is to monitor fuel consumption, Co2 production, and environmental overviews.

"In the current Caretrack system single-cycle data is not available either to Volvo dealer or customer. There is a demand from customers for single cycle production data, but unfortunately, we cannot supply or obtain it"

Nasta AS states that neither cycle times or weight/mass measurements are available on excavators through the PM system ConSite^{TM}. The reason for this being the high flexibility and the unpredictable conditions of excavators in AEC-projects. Such parameters are mainly used on large-scale loading operations. On such large-scale operations, the factory specifications and machine capacity are used to calculate such parameters. The activity mode parameters present in the monthly reports are registered continuously by pressure gauges on the pilot circuit.

Anderaa Data Instruments AS was interviewed in the context of their system LoadTronic 3^{TM} which performs weight measurements on equipment loads. The benefits to such a system

CHAPTER

FIVE

DISCUSSION

This chapter explores the implications of the findings presented in chapter 4 in the context of the objectives and the concepts established in chapter 3.

5.1 What kind of data is collected by PM systems

When discussing **Q1** there are three aspects which presents themselves as significant: *purpose*; *activity modes* and *the level of alteration*.

Purpose

The first aspect, *purpose*, is somewhat implicit to PM systems, which are designed to manage equipment fleets **(see section 3.7)**. The specifics of purpose does however differ depending on the system that is analyzed. It is clear from **chapter 4** that there are indeed differences in what the PM system aims to achieve in terms of services to their users. ConSite^{TM}, for instance, provides the user with weekly singular machine id reports, while CareTrack^{TM} is more concerned with overall fleet management. The parameters provided, along with the timing and frequency of collection and presentation of these to the client is entirely resting upon what the OEM deems important. Attempting to detail the purpose of these PM systems further will only be assumptions and projection, but the fact that there are differences due to purpose will be important in **sections 5.2 and 5.3**.

Activity modes

Section 3.6 described PM systems as an internal system taking advantage of the LES in a non-invasive manner. The parameters discovered in the studied documents had significant differences, this is partly due to differing definitions, compounded parameters and also merely due to differences in the equipment. Although not directly shown, it is pointed out that some technical differences in the equipment might, for instance, dictate how one might categorize different activity modes. This can be argued to be a secondary cause, while the root cause being purpose meaning that the PM system dictates technical specifications. This is not directly part of the scope and is only mentioned to inform the following discussion.

ConSite's^{TM} categorization seems to be aimed towards the approach of calculating productivity since their activity modes clearly distinguish each activity necessary for measuring *Fixed time*, *gross time*, and *effective hours*. CareTrack^{TM} to some extent is also able to measure these parameters through their activity modes, but lacks the required modes to distinguish between *fixed time* and *gross time* which makes the estimation of cycle times much less accurate. The activity modes are, as described in **section 3.6**, essential in terms of calculating CMP accurately.

Level of alteration

The data that is collected by PM systems have been shown to vary depending on the system being used. The parameters acquired from the study of documents **(see section 4.1)** only consisted of stage 2 and stage 3 data **(see figure 3.6).** The level of alteration of the data is of considerable importance since it determines the usefulness of the data in context to ADC systems. In the case of PM systems, once the data is transformed from *stage 1* to *stage 2* and subsequently to *stage 3* there is no way to directly verify this data other than to separately measure the parameter in question and compare. In other words, the details of the transformation of the data between the stages are not available to the client which leads to PM systems being weak in the context of productivity measurement and ADC systems. There is also a concern regarding the accuracy and robustness of the initial measurement which constitutes *stage 1* data. The details of the hardware, sensors, and software in the LES on any construction equipment is not public. This can be attributed to PM systems being a commercialized service where details are considered valuable assets to the providers of said service. It could also be considered a result of disregards for the value of this information from the client's side. There could be a host of reasons, but the important part is that this the details of the LES's data collection are not available to the client or publicly.

5.2 Does the collected data provide sufficient information in regards to calculating productivity

Q2 can be considered the key question since it is most closely related to the main goal. It is also the research question which is easiest to determine unambiguously. Established in **Section 4.2** as a result of the concepts discovered through the literature review, there are two dimensions which decide whether or not the data is sufficient. For an optimal measurement of productivity with the intent of both *progression control* and *productivity improvement* the method needs to exhibit all the required parameters for the calculation of CMP and loading costs as well as all the characteristics of an ADC system.

Required parameters

It was established in **section4.2** that the PM systems examined did in fact not exhibit the required parameters to calculate CMP or loading costs. Standalone, PM systems cannot provide the required parameters **(see table 4.4)**. The table suggests that the parameters required for estimating *Net cycle time*, *Fixed time* and *Loss of time* are only partially present in the PM systems examined. There are two reasons for this, the activity modes which are needed to estimate these factors are present in the PM systems to varying degrees. For instance, ConSite's^{TM} activity modes are able to more accurately estimate these factors than CareTrack^{TM} due to a more comprehensive activity mode categorization. The degree of divergence in accuracy due to the categorization can only be estimated by further quantitative research which is not part of the scope.

The quantity of mass parameter is the only required parameter which is not directly collected by the PM systems examined. Note that some systems provide this feature if add-ons or further subscription options are purchased or opted for. The interviews, however, suggests that most of these add-ons are only available for articulated dump trucks and wheel loaders. Some add-on features like LoadRite^{TM} was discovered for excavators as well as third-party systems such as LoadTronic^{TM} 3E. As discussed in **section 3.2** this requirement is somewhat optional. The quantity of mass can be calculated from capacity, but then carries several uncertainties and possible inaccuracies.

Required characteristics

In regards to meeting the required characteristics of an ADC system the PM systems, as shown in **table 4.5**, lacks several of the key requirements. Both PM systems examined met the requirements for

Automatic and *economical*. As discussed briefly in **section 5.1** the requirements *accurate* and *robust* are definitively not present in the examined PM systems. The *NRT* requirement although not sufficiently met for the set threshold could be considered met if one were to lower the standard of the entire ADC system. One could, for instance, make the ADC system produce the productivity factors once every week, which would be within the confines of for instance the ConSite^{TM} system. The Interview with Volvo AS also revealed that the data provided by their LES's is sent in packages every 24 hours to the production server **(see figure 3.6)**. This makes the CareTrack^{TM} also somewhat eligible for the *NRT* requirement. The interval of which the LES's of Hitachi's excavators send *stage 1* data to their ConSite^{TM} production server is not known, but a similar setup might be the case there as well.

5.3 How is the data collected and used today

The interviews revealed that there were several strategies for measuring productivity, mainly with the intent of progression control. All of the interviewed contractors used their own methods for estimating the production values of their earthmoving operations. OK Entreprenør AS, for instance, took advantage of their MCS to use geometric data to calculate volume. AF Gruppen AS used SmartDok^{TM} to register loading and unloading to estimate loading cycles in conjunction with weight systems on their trucks as a means of measuring productivity. All the interviewed contractors pinpointed compatibility issues as the number one reason for not taking advantage of the PM systems. There were mentioned mainly two main aspects of compatibility issues, differing OEM's and equipment seniority. This means that either is there an incompatibility between different PM systems in the equipment fleet or that there are older machines with outdated versions of these PM systems or a total lack thereof. These result in the same outcome which is that managing the PM systems are harder and more cumbersome than creating a tailor-made system which collects the needed data from other sources. This was the case in all the contractors interviewed. Not only were there compatibility issues, but some stated as well that the PM systems lacked the parameters they were interested in. The total taxonomy of these parameters was not part of the scope and should be researched.

Most of the interviewees stated that services they took advantage of from the PM systems were mainly the following parameters: fuel consumption, fuel efficiency, and CO2 levels. The interviewees stated that these parameters were monitored in an effort to improve them over time and were used in conjunction with their own system of progression control. This was also supported by some of the field experts and providers.

The coordination problem

A typical *coordination problem* has the characteristics of requiring two or more parties to make a chance simultaneously, or at least planned, in order for the system in question to change. As stated in the introduction the purpose of PM systems does not entirely coincide with the requirements this thesis judges them by, but the idea of a PM system fully capable of producing CMP, loading costs and other indicators which are considered of interest to contractors and project managers, does seem like a profitable endeavour for the future of construction. In the context of this and the fact that the current PM systems do not meet the requirements and characteristics of an optimal ADC system due to what in this thesis is assumed to be either company asset valuation, client disregard or both, presents a quite obvious coordination problem. If a change towards PM systems which can provide crucial factors such as CMP, loading costs and other is wanted, which it is most certainly is a good candidate for, several of the OEM's would need to decide that this is a beneficial change and agree to change their policy on the availability of the specifications and details of their respective LES's data collection systems. There is an argument that if one provider made such a change in solitude this change would be recognized and sought after by the clients as the most reasonable choice of OEM since their option provided an ADC system which could provide them with the factors of interest in a clear and manageable format. However, it seems, on the basis of the interviews, unlikely that the contractors would recognize the value immediately which could lead to economic loss for the provider.

Alternatives

Section 3.7 elaborates in short possible external strategies and systems. The literature search revealed that the main field of research on the topic of ADC systems revolves around external strategies and systems. There are promising results in the fields of *Optical recognition*, *Inertia recognition* and *Augmentation of sensory data for increased accuracy*. The PM systems do not meet the requirements set in this thesis for an optimal ADC system with the intent on providing CMP and Loading costs, and although the lack of accuracy and robustness was categorized as *unknown* in **table 4.5** the review of the literature seems to indicate that these could be improved upon. Furthermore, as stated in **section 5.3** there likely are several factors which are of interest to the contractor and project managers, which if incorporated to PM systems could provide additional value, and some of the strategies do present themselves as good candidates for incorporation.

Although the main scope is concerned with PM systems and the potential such systems have, the main field of research seems to be focused on third-party solutions. This not only indicates the industry's recognition of that the purpose and intent of PM systems is not aligned with ADC systems in regards to productivity measure with the intent on productivity improvement. This can also be attributed to the coordination problem discussed in **section 5.3**.

CHAPTER

SIX

CONCLUSSION

The following chapter presents the answers to the research questions put forward in the introduction. As with ***chapter 4 and 5*** *this chapter will have sections in the chronological order in which they appeared in* ***table 1.1****. In addition, the will be a closing section on future work which through this thesis presented itself with potential.*

Firstly, a reminder of the most significant reservation in this thesis. The PM systems examined are not claimed to be specifically designed for the sole purpose of the delivering the services, and requirements thereof **(see section 4.2)**, which they within this thesis is judged by.

6.1 What kind of data is collected by PM systems

Any PM system is a internal system, which means that it is a commercialized system provided by the OEM and that it collects data from the LES. Data compiled by the LES is sent to a production server in packages on specific intervals. During transmission there are algorithms and filtering processes that alter the original data. A categorization for this concept was established, where the level of alteration of the data is determined by three stages. The parameters directly produced by the PM systems client interface are *stage 3* data, while the parameters examined from the production server are *stage 2* data. Since no *stage 1* data was acquired there are certain characteristics and details about the data which cannot be directly determined. For instance the accuracy of the data collection of the LES cannot be determined. This also applies the to robustness of the data since no deviation data could be acquired. The fact that this information could not be acquired, despite considerable effort, suggests that this information is not publicly available. The interviews as well support this claim. The speculation of the cause and reason for this was discussed briefly. However, whatever the reason, the fact that this information is not available either publicly or to the client is a concern in context to the goal of this thesis. This is directly connected to the purpose of such systems. The purpose of the PM systems were briefly discussed, but a definitive conclusion could not be made. The differing purpose between the PM systems and most importantly between the PM systems and the purpose they are judged by in this thesis is however of great significance. The differing purpose mean different requirements for its service provided are actualized. The differing purpose, in unknown degree, results in a misalignment with what an ADC system with intent of measuring productivity for improvement and progression control purposes requires. This fact was somewhat known from the outset, but the details of it matters. Despite the misalignment of purpose and requirements, the PM systems does seem to be capable of providing what is required in the context of what it is judged by in this thesis.

The parameters identified by the two examined PM systems are highly comparable with each other. Most of the parameters identified are present in both systems. There are some differences in definitions of the parameters and some compounded parameters which are not present in both. However, a compounded parameter can easily be produced as long as the composite parts of that parameter are present, which in most cases they seem to be.

activity modes.

6.2 Does the collected data provide sufficient information in regards to calculating productivity

The parameters identified does not, to its full extent, meet the requirements established as necessary for optimal estimation of productivity. The PM systems does provide parameters such as *effective hours*, *total hours* and *fuel consumption* in sufficient detail. As discussed, however, the ultimate accuracy and robustness of these parameters are not determined in this research. Furthermore parameters such as *net cycle time*, *fixed time* and *loss of time* was determined to be partially available to produce from the parameters and their activity modes. The variation in comprehensiveness in the activity mode categorization is the reason these parameters only partially meet the requirements. The capacity to meet the requirements are dependent on the how well the activity modes reflect the real operational activity of the equipment. The studied PM systems activity modes were found to not optimally mimic the real operational activities of the equipment, which leads to uncertainties in the required parameters and thus reduced accuracy.

The studied PM systems were also required to exhibit certain characteristics of ADC systems, and the fulfillment of these was shown to be severely limited. The studied PM systems were found to sufficiently exhibit the characteristics of being *automatic* and *economy*. The characteristic of being *NRT* was determined not to be met under the requirements set in this thesis. The requirement of this characteristic can be argued since the system does provide relative real-time data, that is every 24 hours. The requirement for *NRT* was at least hourly updates. The studied PM systems could not, in any case, provide the required parameters for a full calculation of the productivity on an hourly basis.

The remaining required characteristics *accuracy* and *robustness* were determined to not be determinable based on the findings of this thesis. The fact that these were not determinable suggests that the potential of PM systems today are not compatible with the idea of PM systems as a means of an adequate ADC system with the intent to calculate productivity for *progression control* and *productivity improvement*.

6.3 How is the data collected and used today

The process of producing valuable PIs and progression control analysis's were revealed to consist of *"homemade"* systems incorporating several different strategies. Strategies involved using third-party software and hardware in order to produce valuable indicators of productivity and progression. The methods involved systems such as MC systems, SmartDok^{TM}, PM systems, and Excel^{TM} sheets. It was also discovered that the full potential of the PM systems was not taken advantage of. The PM systems were only used as reference on parameters such as *fuel consumption*, *fuel efficiency* and *CO2 levels*. The reasoning for not taking full advantage of PM system was claimed to be due to severe compatibility issues within the equipment fleet. Aging equipment and differing OEMs was a common occurrence making the PM systems lack practicality due to cumbersome and in some instances impossible conditions of use.

6.4 Main goal conclusion

If a PM system were to be optimally equipped for future use as a tool for productivity calculation with the purpose of *progression control* and *productivity improvement* it needs to provide the required parameters for calculation, as well as exhibiting the required characteristics of an ADC system. This thesis has shown that the current state of PM systems lacks not only some of the required parameters but also some of the key characteristics of a functional ADC system. The PM system is able to provide productivity measures, but some of the activity modes reduce the accuracy. Furthermore, the quantity of mass is not inherently produced by such systems, making the productivity calculation rely on capacity calculations which brings with it several uncertainties and possible inaccuracies as well. Also, the current state of PM systems does not publicly provide the accuracy and robustness of the collected data in a case by case basis, which must be present if a PM system were to be used optimally as an ADC system. The correction of these restrictions requires a coordination problem to be solved. Several of the active industry parties providing such PM systems would need to overcome the initial costs and agree to provide clients, and the public, with full insight of the workings of their systems. This would remedy the problem of these PM systems lacking the necessary characteristics.

The described coordination problem is, however, an unrealistic future for PM systems for obvious reasons such competitiveness and the fact that filling the role of an ADC is not necessarily the only purpose of these PM systems. The conclusion is that ultimately current restrictions severely diminishes the returns if such systems were to be utilized in the proposed way. Lastly, stage 3 data, which is what the client is provided with, is not presented in a format, that is graphs and visualization instead of raw data, which is not easily withdrawn for further use.

To sum up, in their current state the examined PM systems do not provide their clients with systems which meet the required parameters of an ADC system intended for *progression control* and *productivity improvement* optimally. There is a basis for such calculations, but they are deemed, qualitatively, costly in terms of accuracy. Furthermore the data available is not in an easily accessed format, and there are practical issues with compatibility. Although not a reasonable option in their current state, the PM systems do seem to be capable of meeting all the requirements and characteristics if one were to solve the coordination problem.

The ultimate reason for current PM systems lacking such parameters and characteristics is a question of intended purpose and possibly competitive ability. However, this thesis looks past the intended purpose and questions whether or not such systems despite these restrictions could produce the required parameters in an adequate fashion. There are three factors which contribute to the lack of usefulness, in terms of productivity, of the data available to the users of PM system. PM systems are inherently commercialized services owned by the OEM which makes the details of the data acquisition a corporate market value. The PM systems does not provide sufficient parameters for a CMP calculation and the parameters available does not pertain the required characteristics; The conditions of AEC-projects and the equipment fleet of contractors produce several compatibility issues which makes the PM systems lack practicality in its current state.

6.5 Further research

The coordination problem and the misalignment of purpose proposed in this thesis suggest that adopting PM systems as a means of measuring and collecting data for productivity purposes are not feasible unless an industry-wide *lean mentality* arises and the economic purpose of PM companies vanishes. However, several details discovered through this research revealed topics with promising futures in the research field. This thesis was explicitly concerned with excavators in the construction industry. Articulated dump trucks, for instance, have easier access to production amount and cycles times through PM systems and would be an optimal candidate for future research.

Also as discovered through the literature study ADC systems require tailored requirements and characteristics for each activity they are to be applied to, meaning that there not only opportunities for research on what these requirements need to be in each distinct work operations, but also how to correctly combine them work in harmony for an entire project. Furthermore, in the context of this, there are opportunities for such ADC systems to be merged with BIM for an overall project interface monitoring not only project performance in 4D but also productivity improvement in the same context.

As mentioned the CMP and loading costs of construction activities are not the only valuable information, a survey of the most valued factors along with its matching method of acquirement could prove useful in the context of continuously striving for ideal productivity.

Lastly, the literature study revealed that large amounts of the research field are centered around singular external methods of ADC. There are considerable opportunities for investigating fully operational ADC systems with the intent of *progression control* and *productivity improvement* by combining external methods.

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Appendix

The appendix is comprised of X attachments:

1. ”Stage 0 - Pre-study pool”
2. ”Stage 1 - Initial search”
3. ”Stage 1 - Finalized pool”
4. ”Stage 2 - Study selection”
5. ”Stage 3 - Charting the data, final pool”
6. ”Stage 3 - CAOS-Evaluation”
7. ”Interview report: Nasta AS ”
8. ”Interview report: Volvo AS ”
9. ”Interview report: Oppdal Maskinkompani AS ”
10. ”Interview report: Gundersen og Løken AS”
11. ”Interview report: Aanderaa Data instruments AS”
12. ”Interview report: OK Entreprenør AS”
13. ”Interview report: AF Gruppen AS ”
14. ”Interview Guide ”
15. ”Weekly Fuel effieciency report: Caretrack, Tvedestrand-Arendal forbindelsen - AF Gruppen AS”
16. ”Monthly Fuel effieciency report: Caretrack, Tvedestrand-Arendal forbindelsen - AF Gruppen AS”
17. ”Machine Operating control report: Consite, Nasta AS”
18. ”Fuel report history: Volvo AS”

Attachment 1: Stage 0 - Pre-study: Selection from Automation in Construction

Author(s)	Title	Key Words	Year	Source	Publisher	Type document	Peak of interest	DOI	Light read interest
S. Dadhich U. Bodin U. Andersson	Key challenges in automation of earth-moving machines	Earth-moving Automation Loader Short loading cycle	2016	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2016.05.009	High relevance, general challenges
Kurt M. Lundeen Suyang Dong Nicholas Fredricks Manu Akula Jongwon Seo Vineet R. Kamat	Optical marker-based end effector pose estimation for articulated excavators	Camera-marker network Pose estimation Machine control Equipment monitoring Construction equipment Articulated machines Excavator guidance Grade control	2016	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2016.02.003	High relevance, photo- machine-recognition
Hakgu Kim Seungjin Yoo Sungwoo Cho Kyongsu Yi	Hybrid control algorithm for fuel consumption of a compound hybrid excavator	Compound hybrid excavator Power management Optimal control	2016	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2016.03.017	Low relevance, power saving with hybrid drive
Yu Du Michael C. Dorneich Brian Steward	Virtual operator modeling method for excavator trenching	Human operator modeling Construction machinery Excavator trenching-machinery operations Model-based design Virtual prototyping	2016	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2016.06.013	High relevance, why robotic construction machinery is hard
Quang Hoan Le Jae Woo Lee Soon Yong Yang	Remote control of excavator using head tracking and flexible monitoring method	Excavator Remote control Head tracking Head mounted display Smart observation	2017	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2017.06.015	High relevance, remote control setup
Kurt M. Lundeen Vineet R. Kamat Carol C. Menassa Wes McGee	Scene understanding for adaptive manipulation in robotized construction work	Construction automation Construction robotics Robot perception Scene understanding Model fitting Construction feature modeling Clustering and Iterative Closest Point Generalized Resolution Correlative Scan Matching	2017	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2017.06.022	High relevance, why robotic construction machinery is hard
Mohammad Mostafa Soltani Zhenhua Zhu Amin Hammad	Skeleton estimation of excavator by detecting its parts	Part recognition Synthetic images Auto-annotation Skeleton estimation Pose estimation	2017	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2017.06.023	High relevance, photo- machine-recognition
Hua Zhou Peng-Yu Zhao Ying-Long Chen Hua-Yong Yang	Prediction-based stochastic dynamic programming control for excavator	Hybrid power Excavator Load prediction Dynamic programming control strategy	2017	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2017.08.014	High relevance, Fuel consumption control
Frank A. Bender Marcel Mitschke Thomas Bräunl Oliver Sawodny	Predictive operator modeling for virtual prototyping of hydraulic excavators	Hydraulic excavator Operator modeling Virtual prototype Simulation Model predictive control Optimization	2017	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2017.08.008	Medium relevance, virtual and predictive creation of excavators
Hong-Chul Lee Han-Seong Gwak Jongwon Seo Dong-Eun Lee	Eco-economic excavator configuration method	Excavator Eco-economic performance Working attachments Optimization	2017	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2017.11.006	Semi-high relevance, formula for selecting the right machines and modes for a project
Jinwoo Kim Seokho Chi Jongwon Seo	Interaction analysis for vision-based activity identification of earthmoving excavators and dump trucks	Vision-based Activity identification Interaction Earthmoving operatrion Excavator Dump truck	2018	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2017.12.016	Semi-high relevance, photo-machine-recognition
Hyunsoo Kim Changbum R. Ahn David Engelhaupt SangHyun Lee	Application of dynamic time warping to the recognition of mixed equipment activities in cycle time measurement	Cycle-time Construction equipment Smartphone Inertial measurement unit (IMU) Dynamic time warping (DTW)	2018	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2017.12.014	High relevance, cycletime analysis
Jongwon Seo Seungsoo Lee Jeonghwan Kim Sung-Keun Kim	Task planner design for an automated excavation system	Automation Earthwork Intelligent excavation system Task planning system	2011	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2011.03.013	High relevance, Fully automated excavator
Nipesh Pradhananga Jochen Teizer	Automatic spatio-temporal analysis of construction site equipment operations using GPS data	Construction equipment operation Cyclic activities Data visualization Global positioning system (GPS) Information modeling Proximity Productivity Safety	2013	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2012.09.004	High relevance, GPS location analysis
Rashi Tiwari Jeremy Knowles George Danko	Bucket trajectory classification of mining excavators	Mining Excavator Trajectory Bucket	2013	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2012.11.006	Low/no relevance
S. Šalinić G. Bošković, M. Nikolić	Dynamic modelling of hydraulic excavator motion using Kane's equations	Hydraulic excavator Dynamics Multibody Deformable soil foundation	2014	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2014.03.024	High relevance, Motion calculation
Tao Wang Qingfeng Wang	Efficiency analysis and evaluation of energy-saving pressure-compensated circuit for hybrid hydraulic excavator	Energy recovery Efficiency analysis Hydraulic cylinder Excavator Pressure compensation	2014	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2014.07.012	Low/no relevance
Jungho Yoon Jeonghwan Kim Jongwon Seo Sangwook Suh	Spatial factors affecting the loading efficiency of excavators	Excavator Spatial factors Truck loading	2014	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2014.08.002	High relevance, spatial loading factors
Ryder C. Winck Mark Elton Wayne J. Book	A practical interface for coordinated position control of an excavator arm	Coordinated control Human–machine interface Kinematically similar joystick Hydraulic manipulators Excavators Human factors	2015	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2014.12.012	Medium relevance
Xun Chen Fuqian Chen Jun Zhou Lihong Li Yanliang Zhang	Cushioning structure optimization of excavator arm cylinder	Cushioning performance Structural optimization Multi-domain simulation model Excavator arm cylinder	2015	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2015.03.012	Low/no relevance
Faridaddin Vahdatikhaki Amin Hammad Hassaan Siddiqui	Optimization-based excavator pose estimation using real-time location systems	Pose estimation Optimization RTLS Excavator	2015	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2015.03.006	High relevance, up-to-date positioning systems
Dongyun Wang Lijuan Zheng Hongxiang Yu Wu Zhou Liping Shao	Robotic excavator motion control using a nonlinear proportional-integral controller and cross-coupled pre-compensation	Hydraulic excavator Coordinated control Pre-compensation Tracking error	2016	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2015.12.024	Medium relevance, tracking improvements
Steven J. Lorenc Leonhard E. Bernold	Excavator-mounted ordnance locating system using electromagnetic sensing technology	Automation Robotics Remediation Unexploded ordnance	1998	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/S0926-5805(97)00069-1	low/medium relevance, metal detector on bucket tech
Tianliang Lin Qingfeng Wang Baozan Hu Wen Gong	Research on the energy regeneration systems for hybrid hydraulic excavators	Hybrid system Excavator Energy regeneration system Energy saving	2010	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2010.08.002	Low relevance, power saving with hybrid drive
Tianliang Lin Qingfeng Wang Baozan Hu Wen Gong	Development of hybrid powered hydraulic construction machinery	Hybrid system Excavator Wheel loader Energy regeneration Energy saving Construction machinery	2010	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2009.09.005	Low relevance, power saving with hybrid drive
Dongyun Wang Cheng Guan Shuangxia Pan Minjie Zhang Xiao Lin	Performance analysis of hydraulic excavator powertrain hybridization	Energy saving Hydraulic excavator Hybrid technology The parallel configuration The series configuration	2009	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2008.10.001	Low relevance, power saving with hybrid drive
Dongmok Kim Jongwon Kim Kyouhee Lee Cheolgyu Park Jinsuk Song Deuksoo Kang	Excavator tele-operation system using a human arm	Tele-operation Excavator Orientation sensor Master/slave control system	2009	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2008.07.002	Low relevance

Qing Xiao Qingfeng Wang Yanting Zhang	Control strategies of power system in hybrid hydraulic excavator	Hybrid system Excavator Engine constant-work-point control strategy Double-work-point control strategy Dynamic-work-point control strategy	2008	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2007.05.014	Low relevance, power saving with hybrid drive
Tadeusz Smolnicki Damian Derlukiewicz Mariusz Stańco	Evaluation of load distribution in the superstructure rotation joint of single-bucket caterpillar excavators	Slewing bearing Truck excavator Finite element method Nonlinear contact	2008	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2007.05.003	Not relevant
R. Navon	Research in automated measurement of project performance indicators	Automation Data collection Feedback control Control methods Monitoring	2007	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2006.03.003	High relevance, general info regarding automation
Tomi Makkonen Kelervo Nevala Rauno Heikkila	A 3D model based control of an excavator	Robotic excavator Path generation Dig planning; Modelling Simulation Triangular terrain model CAD	2006	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2005.07.009	Fully automatic excavator using CAD
Ger Maas Frans van Gassel	The influence of automation and robotics on the performance construction	Value creation Performance management Construction engineering Construction management Automation Metropolis	2005	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/j.autcon.2004.09.010	Low relevance, A look at the larger changes that comes with digitisation
Q.P. Ha Q.H. Nguyen D.C. Rye H.F. Durrant-Whyte	Impedance control of a hydraulically actuated robotic excavator	Robotic excavator Hybrid positionrforce control Sliding controller	2000	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/S0926-5805(00)00056-X	High relevance, Model for positioning and force calculation
Rafal Klaus Andrzej Urbaniak	Safety algorithms for excavator engine control	Computer control Diesel engine Automatic testing Redundancy Safety analysis	1998	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/S0926-5805(98)00043-0	automated "safety pin" for not exceeding rpm limits in order to prevent a burnt out engine
L. Płonecki W. Tra¸mpczynski J. Cendrowicz	A concept of digital control system to assist the operator of hydraulic excavators	Digital control system Hydraulic excavators Tool trajectories	1998	Automation in Construction	Elsevier	Journal article	Initial title interest	https://doi.org/10.1016/S0926-5805(98)00045-4	Medium relevance, Control assistance rather than actual post work data generation

Attachment 2: Stage 1 - search

Search term - Tags in Subject/title/abstract	Filter(s) + Search Code	Sorted by	Total # of hits	# of hits considered relevant	Author(s)	Title	Year	Remarks	DIO
"Machine" AND "control" AND "systems"	Journal article, English, No duplicates SearchCode: ((((((((Machine control systems) WN KY)) AND ({ja} WN DT)) AND ((cpx) WN DB)))) AND ({english} WN LA))	Relevance	47398	Unknown				Nonacceptable size, pool reduction required. Removing duplicates not adequate	
"Machine Control systems"	Journal article, English, No duplicates SearchCode: ((((("machine control systems") WN KY)) AND ((({ca} OR {ja}) WN DT) AND ({english} WN LA))) AND ({ja} WN DT))	Relevance	134	1				Acceptable size, approved for inspection	
					Esa Viljamaa Irina Peltomaa	Intensified construction process control using information integration	2013	Considered relevant	10.1016/j.autcon.2013.08.015
"Machine Control systems" AND "excavator"	Journal article, English, No duplicates SearchCode: (((("machine control systems" AND "excavator") WN KY)) AND (({ja} WN DT) AND ({english} WN LA)))	Relevance	1	1				Acceptable size, approved for inspection	
					Makkonen, T. Nevala, K. Heikkila, R.	A 3D model based control of an excavator	2006	Considered relevant	10.1016/j.autcon.2005.07.009
"Machine" AND "Control" AND "systems" AND "excavator"	Journal article, English, No duplicates SearchCode: (((("machine" AND "control" AND "systems" AND "excavator") WN KY)) AND (({ja} WN DT) AND ({english} WN LA)))	Relevance	49	6				Acceptable size, approved for inspection	
					Koivo, A.J. Thoma, M. Kocaoglan, E. Andrade-Cetto, J.	Modeling and control of excavator dynamics during digging operation	1996	Considered relevant	10.1061/(ASCE)0893-1321(1996)9:1(10)
					Sepehri, N. Lawrence, P.D. Sassani, F. Frenette, R.	Resolved-mode teleoperated control of heavy-duty hydraulic machines	1994	Considered relevant	10.1115/1.2899215
					Ha, Quang Santos, Miguel Nguyen, Quang Rye, David Durrant-Whyte, Hugh	Robotic excavation in construction automation	2002	Considered relevant	10.1109/100.993151
					Plonecki, L. Trampczynski, W. Cendrowicz, J.	A concept of digital control system to assist the operator of hydraulic excavators	1998	Considered relevant	10.1016/S0926-5805(98)00045-4
					Jun Gu Taylor, J. Seward, D.	Modelling of an hydraulic excavator using simplified refined instrumental variable (SRIV) algorithm	2007	Considered relevant	10.1007/s11768-006-6180-2
					Budny, Eugeniusz Chłosta, Mirosław Gutkowski, Witold	Load-independent control of a hydraulic excavator	2003	Considered relevant	10.1016/S0926-5805(02)00088-2
"machine" AND "control" AND "computer" AND "parameters"	Journal article, English, No duplicates SearchCode: ((((("machine" AND "control" AND "computer" AND "parameters") WN KY)) AND ((({ja} WN DT) AND ({english} WN LA))) AND ({ja} WN DT))	Relevance	2298	Unknown				Nonacceptable size, pool reduction required. Removing duplicates not adequate	
"Machine" AND "Control" AND "computer" AND "parameters" AND "construction"	Journal article, English, No duplicates SearchCode: ((((("machine" AND "control" AND "computer" AND "parameters" AND "construction") WN KY)) AND (({ja} WN DT) AND ({english} WN LA))) AND ({ja} WN DT))	Relevance	54	0				Acceptable size, approved for inspection, but no relevant articles found	
"Machine" AND "Control" AND "computer" AND "parameters" AND "productivity"	Journal article, English, No duplicates SearchCode: ((((("machine" AND "control" AND "computer" AND "parameters" AND "productivity") WN KY)) AND (({ja} WN DT) AND ({english} WN LA))) AND ({ja} WN DT))	Relevance	57	0				Acceptable size, approved for inspection, but no relevant articles found	
"excavator" AND "earthmoving" AND "productivity"	Journal article, English, No duplicates SearchCode: (((("excavator" and "earthmoving" AND "productivity") WN KY)) AND (({ja} WN DT) AND ({english} WN LA)))	Relevance	9	1				Acceptable size, approved for inspection	
					Montaser, Ali Bakry, Ibrahim Alshibani, Adel Moselhi, Osama	Estimating productivity of earthmoving operations using spatial technologies	2012	Considered relevant	10.1139/l2012-059
"excavator" AND "measurement" AND "productivity"	Journal article, English, No duplicates SearchCode: (((("excavator" and "measurement" AND "productivity") WN KY)) AND (({ja} WN DT) AND ({english} WN LA)))	Relevance	6	0				Acceptable size, approved for inspection, but no relevant articles found	
"excavator "AND "parameters" AND "productivity"	Journal article, English, No duplicates SearchCode: (((("excavator" and "parameters" AND "productivity") WN KY)) AND (({ja} WN DT) AND ({english} WN LA)))	Relevance	8	0				Acceptable size, approved for inspection, but no relevant articles found	
"Automation" and "productivity" AND "construction"	Journal article, English, No duplicates SearchCode: (((("Automation" and "productivity" AND "construction") WN KY)) AND (({ja} WN DT) AND ({english} WN LA)))	Relevance	226	8				Acceptable size, approved for inspection	
					Isaac, Shabtai Navon, Ronie	Can project monitoring and control be fully automated?	2014	Considered relevant	10.1080/01446193.2013.795653
					Singh, S.	State of the art in automation of earthmoving	1997	Considered relevant	10.1061/(ASCE)0893-1321(1997)10:4(179)
					Ibrahim, Magdy Moselhi, Osama	Automated productivity assessment of earthmoving operations	2014	Considered relevant	https://www.itcon.org/paper/2014/9
					Shah, Raj Kapur	A new approach for automation of location-based earthwork scheduling in road construction projects	2014	Considered relevant	10.1016/j.autcon.2014.03.003
					Sanvido, Victor E. Medeiros, Deborah J.	Applying computer-integrated manufacturing concepts to construction	1990	Considered relevant	10.1061/(ASCE)0733-9364(1990)116:2(365)
					Everett, John G. Slocum, Alexander H.	Automation and robotics opportunities: Construction versus manufacturing	1994	Considered relevant	10.1061/(ASCE)0733-9364(1994)120:2(443)
					Gong, Jie Caldas, Carlos H.	An object recognition, tracking, and contextual reasoning-based video interpretation	2011	Considered relevant	10.1016/j.autcon.2011.05.005
					Zhai, Dong Goodrum, Paul M. Haas, Carl T. Caldas, Carlos H.	Relationship between automation and integration of construction information systems and labor productivity	2009	Considered relevant	10.1061/(ASCE)CO.1943-7862.0000024
"excavator" and "loading"	Journal article, English, No duplicates SearchCode: (((("excavator" and "loading") WN KY)) AND (({ja} WN DT) AND ({english} WN LA)))	Relevance	117	1				Acceptable size, approved for further inspection of pool	

					Qingyuan Zhu Yuanhui Liu Huosheng Hu Liang Hou Mingjie Guan	Using wavelet denoising in automatic online efficiency estimation of a hydraulic excavator	2017	Considered relevant	DOI:10.1177/0142331216634428;
"excavator" and "loading" and "measurement"	Journal article, English, No duplicates SearchCode: (((("excavator" and "loading" and "measurement") WN KY)) AND (({ja} WN DT) AND ({english} WN LA)))	Relevance	6	0				Acceptable size, approved for inspection, but no relevant articles found	
"excavator" and "loading" and "measurement"	Journal article, English, No duplicates SearchCode: (((("excavator" and "loading" and "measurement") WN KY)) AND (({ja} WN DT) AND ({english} WN LA)))	Relevance	9	0				Acceptable size, approved for inspection, but no relevant articles found	
"performance monitoring" and "construction"	Journal article, English, No duplicates SearchCode: (((("performance monitoring" and "construction") WN KY)) AND (({ja} WN DT) AND ({english} WN LA)))	Relevance	172	6				Acceptable size, approved for further inspection of pool	
					Abdi, Abdollah Taghipour, Sharareh Khamooshi, Homayoun	A model to control environmental performance of project execution process based on greenhouse gas emissions using earned value management	2018	Considered relevant	10.1016/j.ijproman.2017.12.003
					Memarzadeh, Milad Golparvar-Fard, Mani Niebles, Juan Carlos	Automated 2D detection of construction equipment and workers from site video streams using histograms of oriented gradients and colors	2013	Considered relevant	10.1016/j.autcon.2012.12.002
					Chiu, Chao-Ying Russell, Alan D.	Design of a construction management data visualization environment: A top-down approach	2011	Considered relevant	10.1016/j.autcon.2010.11.010
					Golparvar-Fard, Mani Bohn, Jeffrey Teizer, Jochen Savarese, Silvio Peña-Mora, Feniosky	Evaluation of image-based modeling and laser scanning accuracy for emerging automated performance monitoring techniques	2011	Considered relevant	10.1016/j.autcon.2011.04.016
					Cheung, Sai On Suen, Henry C.H. Cheung, Kevin K.W.	PPMS: A Web-based construction Project Performance Monitoring System	2004	Considered relevant	10.1016/j.autcon.2003.12.001
					Yang, Jun Park, Man-Woo Vela, Patricio A. Golparvar-Fard, Mani	Construction performance monitoring via still images, time-lapse photos, and video streams: Now, tomorrow, and the future	2015	Considered relevant	10.1016/j.aei.2015.01.011
"construction" AND "machine" AND "monitoring	Journal article, English, No duplicates SearchCode: (((("construction" AND "machine" AND "monitoring") WN KY)) AND (({ja} WN DT) AND ({english} WN LA)))	Relevance	209	6				Acceptable size, approved for further inspection of pool	
					Vondrackova, T. Sip, M. Caha, Z.	Application of information technologies to fuel savings in construction	2015	Considered relevant	10.4028/www.scientific.net/AMM.803.89
					Maas, G. van Gassel, F.	The influence of automation and robotics on the performance construction	2005	Considered relevant	10.1016/j.autcon.2004.09.010
					Dimitrov, A. Golparvar-Fard, M.	Vision-based material recognition for automated monitoring of const ruction progress and generating building information modeling from unordered site image collections	2014	Considered relevant	10.1016/j.aei.2013.11.002
					Louis, J. Dunston, P.S.	Methodology for real-time monitoring of constructio n operations using finite state machines and discrete-event operation models	2017	Considered relevant	10.1061/(ASCE)CO.1943-7862.0001243
			#articles:	30					

Attachment 3: Stage 0 - Pre-study: Selection from Automation in Construction

Author(s)	Title	Year	Source	Publisher	Type document	DOI	Backwards citation chaining
From manual Search of Automation in Construction							
S. Dadhich U. Bodin U. Andersson	Key challenges in automation of earth-moving machines	2016	Automation in Construction	Elsevier	Journal article	https://doi.org/10.1016/j.autcon.2016.05.009	No relevant articles found
Kurt M. Lundeen Suyang Dong Nicholas Fredricks Manu Akula Jongwon Seo Vineet R. Kamat	Optical marker-based end effector pose estimation for articulated excavators	2016	Automation in Construction	Elsevier	Journal article	https://doi.org/10.1016/j.autcon.2016.02.003	No relevant articles found
Yu Du Michael C. Dorneich Brian Steward	Virtual operator modeling method for excavator trenching	2016	Automation in Construction	Elsevier	Journal article	https://doi.org/10.1016/j.autcon.2016.06.013	No relevant articles found
Quang Hoan Le Jae Woo Lee Soon Yong Yang	Remote control of excavator using head tracking and flexible monitoring method	2017	Automation in Construction	Elsevier	Journal article	https://doi.org/10.1016/j.autcon.2017.06.015	No relevant articles found
Kurt M. Lundeen Vineet R. Kamat Carol C. Menassa Wes McGee	Scene understanding for adaptive manipulation in robotized construction work	2017	Automation in Construction	Elsevier	Journal article	https://doi.org/10.1016/j.autcon.2017.06.022	No relevant articles found
Mohammad Mostafa Soltani Zhenhua Zhu	Skeleton estimation of excavator by detecting its parts	2017	Automation in Construction	Elsevier	Journal article	https://doi.org/10.1016/j.autcon.2017.06.023	No relevant articles found
Hua Zhou Peng-Yu Zhao Ying-Long Chen Hua-Yong Yang	Prediction-based stochastic dynamic programming control for excavator	2017	Automation in Construction	Elsevier	Journal article	https://doi.org/10.1016/j.autcon.2017.08.014	Relevant article(s) found (#1)
Hong-Chul Lee Han-Seong Gwak Jongwon Seo Dong-Eun Lee	Eco-economic excavator configuration method	2017	Automation in Construction	Elsevier	Journal article	https://doi.org/10.1016/j.autcon.2017.11.006	Relevant article(s) found (#4)
Jinwoo Kim Seokho Chi Jongwon Seo	Interaction analysis for vision-based activity identification of earthmoving excavators and dump trucks	2018	Automation in Construction	Elsevier	Journal article	https://doi.org/10.1016/j.autcon.2017.12.016	No relevant articles found
Hyunsoo Kim Changbum R. Ahn David Engelhaupt SangHyun Lee	Application of dynamic time warping to the recognition of mixed equipment activities in cycle time measurement	2018	Automation in Construction	Elsevier	Journal article	https://doi.org/10.1016/j.autcon.2017.12.014	Relevant article(s) found (#3)
Jongwon Seo Seungsoo Lee Jeonghwan Kim Sung-Keun Kim	Task planner design for an automated excavation system	2011	Automation in Construction	Elsevier	Journal article	https://doi.org/10.1016/j.autcon.2011.03.013	No relevant articles found
Nipesh Pradhananga Jochen Teizer	Automatic spatio-temporal analysis of construction site equipment operations using GPS data	2013	Automation in Construction	Elsevier	Journal article	https://doi.org/10.1016/j.autcon.2012.09.004	No relevant articles found
S. Šalinić G. Bošković, M. Nikolić	Dynamic modelling of hydraulic excavator motion using Kane's equations	2014	Automation in Construction	Elsevier	Journal article	https://doi.org/10.1016/j.autcon.2014.03.024	No relevant articles found
Jungho Yoon Jeonghwan Kim Jongwon Seo Sangwook Suh	Spatial factors affecting the loading efficiency of excavators	2014	Automation in Construction	Elsevier	Journal article	https://doi.org/10.1016/j.autcon.2014.08.002	No relevant articles found
Faridaddin Vahdatikhaki Amin Hammad Hassaan Siddiqui	Optimization-based excavator pose estimation using real-time location systems	2015	Automation in Construction	Elsevier	Journal article	https://doi.org/10.1016/j.autcon.2015.03.006	Relevant article(s) found (#1)
Dongyun Wang Lijuan Zheng Hongxiang Yu Wu Zhou Liping Shao	Robotic excavator motion control using a nonlinear proportional-integral controller and cross-coupled pre-compensation	2016	Automation in Construction	Elsevier	Journal article	https://doi.org/10.1016/j.autcon.2015.12.024	No relevant articles found
Steven J. Lorenc Leonhard E. Bernold	Excavator-mounted ordnance locating system using electromagnetic	1998	Automation in Construction	Elsevier	Journal article	https://doi.org/10.1016/S0926-5805(97)00069-1	No relevant articles found
R. Navon	Research in automated measurement of	2007	Automation in Construction	Elsevier	Journal article	https://doi.org/10.1016/j.autcon.2006.03.003	Relevant article(s) found (#3)
Q.P. Ha Q.H. Nguyen D.C. Rye H.F. Durrant-Whyte	Impedance control of a hydraulically actuated robotic excavator	2000	Automation in Construction	Elsevier	Journal article	https://doi.org/10.1016/S0926-5805(00)00056-X	No relevant articles found
From literature search							
Esa Viljamaa Irina Peltomaa	Intensified construction process control using information	2013	Automation in Construction	Elsevier B.V., Netherlands	Journal article	10.1016/j.autcon.2013.08.015	Relevant article(s) found (#2)
Makkonen, T. Nevala, K. Heikkila, R.	A 3D model based control of an excavator	2006	Automation in Construction	Elsevier, Netherlands	Journal article	10.1016/j.autcon.2005.07.009	No relevant articles found
Koivo, A.J. Thoma, M. Kocaoglan, E. Andrade-Cetto, J.	Modeling and control of excavator dynamics during digging operation	1996	Journal of Aerospace Engineering	ASCE	Journal article	10.1061/(ASCE)0893-1321(1996)9:1(10)	No relevant articles found
Sepehri, N. Lawrence, P.D. Sassani, F. Frenette, R.	Resolved-mode teleoperated control of heavy-duty hydraulic machines	1994	Journal of Dynamic Systems, Measurement, and Control	The American Society of Mechanical Engineers	Journal article	10.1115/1.2899215	No relevant articles found
Ha, Quang Santos, Miguel Nguyen, Quang Rye, David Durrant-Whyte, Hugh	Robotic excavation in construction automation	2002	IEEE Robotics & Automation Magazine	Institute of Electrical and Electronics Engineers Inc	Journal article	10.1109/100.993151	No relevant articles found
"Plonecki, L. Trampczynski, W. Cendrowicz, J."	A concept of digital control system to assist the operator of hydraulic excavators	1998	Automation in Construction	Elsevier, Netherlands	Journal article	10.1016/S0926-5805(98)00045-4	No relevant articles found

Jun Gu Taylor, J. Seward, D.	Modelling of an hydraulic excavator using simplified refined instrumental variable (SRIV)	2007	Journal of Control Theory and Applications		Journal article	10.1007/s11768-006-6180-2	No relevant articles found
Montaser, Ali Bakry, Ibrahim Alshibani, Adel Moselhi, Osama	Estimating productivity of earthmoving operations using spatial technologies	2012	Canadian Journal of Civil Engineering	National Research Council of Ca nada, Canada	Journal article	10.1139/l2012-059	No relevant articles found, No access
Isaac, Shabtai Navon, Ronie	Can project monitoring and control be fully automated?	2014	Construction Management and Economics	Routledge	Journal article	10.1080/01446193.2013.795653	Relevant article(s) found (#1)
Singh, S.	State of the art in automation of earthmoving	1997	Journal of Aerospace Engineering	ASCE	Journal article	10.1061/(ASCE)0893-1321(1997)10:4(179)	No relevant articles found
Ibrahim, Magdy Moselhi, Osama	Automated productivity assessment of earthmoving operations	2014	Electronic Journal of Information Technology in Construction	Royal Institute of |Technology, Sweden	Journal article	https://www.itcon.org/paper/2014/9	No relevant articles found
Shah, Raj Kapur	A new approach for automation of location-based earthwork scheduling in road construction	2014	Automation in Construction	Elsevier B.V., Netherlands	Journal article	10.1016/j.autcon.2014.03.003	No relevant articles found
Sanvido, Victor E. Medeiros, Deborah J.	Applying computer-integrated manufacturing concepts to construction	1990	Journal of Construction Engineering and Management	ASCE	Journal article	10.1061/(ASCE)0733-9364(1990)116:2(365)	No relevant articles found, old
Everett, John G. Slocum, Alexander H.	Automation and robotics opportunities: Construction versus manufacturing	1994	Journal of Construction Engineering and Management	ASCE	Journal article	10.1061/(ASCE)0733-9364(1994)120:2(443)	No relevant articles found, old
Gong, Jie Caldas, Carlos H.	An object recognition, tracking, and contextual reasoning-based video interpretation method for rapid productivity analysis of construction	2011	Automation in Construction	ASCE	Journal article	10.1016/j.autcon.2011.05.005	No relevant articles found
Zhai, Dong Goodrum, Paul M. Haas, Carl T. Caldas, Carlos H.	Relationship between automation and integration of construction information systems and labor productivity	2009	Journal of Construction Engineering and Management	ASCE	Journal article	10.1061/(ASCE)CO.1943-7862.0000024	No relevant articles found
Qingyuan Zhu Yuanhui Liu Huosheng Hu Liang Hou Mingjie Guan	Using wavelet denoising in automatic online efficiency estimation of a hydraulic excavator	2017	Transactions of the Institute of Measurem ent and Control	SAGE Publicat	Journal article	10.1177/0142331216634428	No relevant articles found
Abdi, Abdollah Taghipour, Sharareh Khamooshi, Homayoun	A model to control environmental performance of project execution process based on greenhouse gas emissions using earned value management	2018	International Journal of Project Managemen t	Elsevier Ltd	Journal article	10.1016/j.ijproman.2017.12.003	No relevant articles found
Memarzadeh, Milad Golparvar-Fard, Mani Niebles, Juan Carlos	Automated 2D detection of construction equipment and workers from site video streams using histograms of oriented	2013	Automation in Construction	Elsevier B.V., Netherlands	Journal article	10.1016/j.autcon.2012.12.002	No relevant articles found
Chiu, Chao-Ying Russell, Alan D.	Design of a construction management data visualization environment: A top-down approach	2011	Automation in Construction	Elsevier	Journal article	10.1016/j.autcon.2010.11.010	No relevant articles found
Golparvar-Fard, Mani Bohn, Jeffrey Teizer, Jochen Savarese, Silvio Peña-Mora, Feniosky	Evaluation of image-based modeling and laser scanning accuracy for emerging automated performance monitoring techniques	2011	Automation in Construction	Elsevier B.V., Netherlands	Journal article	10.1016/j.autcon.2011.04.016	No relevant articles found
Cheung, Sai On Suen, Henry C.H. Cheung, Kevin K.W.	PPMS: A Web-based construction Project Performance Monitoring System	2004	Automation in Construction	Elsevier, Netherlands	Journal article	10.1016/j.autcon.2003.12.001	No relevant articles found
Yang, Jun Park, Man-Woo Vela, Patricio A. Golparvar-Fard, Mani	Construction performance monitoring via still images, time-lapse photos, and video streams: Now, tomorrow, and the future	2015	Advanced Engineering Informatics	Elsevier B.V., Netherlands	Journal article	10.1016/j.aei.2015.01.011	No relevant articles found
Vondrackova, T. Sip, M. Caha, Z.	Application of information technologies to fuel savings in construction	2015	Applied Mechanics and Materials	Trans Tech Publications, Switzerland	Journal article	10.4028/www.scientific.net/AMM.803.89	No relevant articles found
Maas, G. van Gassel, F.	The influence of automation and robotics on the	2005	Automation in Construction	Elsevier, Netherlands	Journal article	10.1016/j.autcon.2004.09.010	No relevant articles found
Dimitrov, A. Golparvar-Fard, M.	Vision-based material recognition for automated monitoring of constructi on progress and generating building information modeling from	2014	Advanced Engineering Informatics	Elsevier B.V., Netherlands	Journal article	10.1016/j.aei.2013.11.002	No relevant articles found
Louis, J. Dunston, P.S.	Methodology for real-time monitoring of construction op erations using finite state machines and discrete-event operation	2017	Journal of Construction Engineering and Management	ASCE	Journal article	10.1061/(ASCE)CO.1943-7862.0001243	No relevant articles found
From backwards citation chaning							
Salmasi, Farzad Rajaei	Control strategies for hybrid electric vehicles: Evolution, classification, comparison, and futuretrends	2007	IEEE Transactions on Vehicular Technology	Institute of Electrical and Electronics Engineers Inc	Journal article	10.1109/TVT.2007.899933	Only one iteration of citation chaing was deemed necesarry
DAVID J. EDWARDS GARY D. HOLT	a model for calculating excavator productivity and output costs	2000	Engineering, Construction and Architectural Management	MCB UP Ltd	Journal article	10.1108/eb021132	Only one iteration of citation chaing was deemed necesarry
Junli, Yanga David, Jedwardsa Peter E.D, Love	A computational intelligent fuzzy model approach for excavator cycle time simulation	2003	Automation in Construction		Journal article	10.1016/S0926-5805(03)00056-6	Only one iteration of citation chaing was deemed necesarry

Azar, E.R. Dickinson, S. McCabe, B.	Server- Customer Interaction Tracker: Com puter Vision- Based System to Estimate Dirt- LoadingCycles	2013	Journal of Construction Engineering & Management	American Society of Civil Engineers, USA	Journal article	10.1061/(ASCE)CO.1943-7862.0000652	Only one iteration of citation chaing was deemed necesarry
Kannan, Govindan	Field studies in construction equipment economics and productivity	2011	Journal of Construction Engineering and Management	ASCE	Journal article	10.1061/(ASCE)CO.1943-7862.0000335	Only one iteration of citation chaing was deemed necesarry
Navon, R.	Automated project performance control of construction projects	2005	Automation in Construction	ASCE	Journal article	10.1016/j.autcon.2004.09.006	Only one iteration of citation chaing was deemed necesarry
Ahn, C.R. SangHyun Lee Pena-Mora, F.	Application of Low-Cost Accelerometers for Measuring the Operational Efficiency of a	2015	Journal of Computing in Civil Engineering	ASCE	Journal article	10.1061/(ASCE)CP.1943-5487.0000337	Only one iteration of citation chaing was deemed necesarry
Mathur, N. Aria, S.S. Adams, T. Ahn, C.R. Lee, S.	Automated Cycle Time Measurement and Analysis of Excav ator's Loading Operation UsingSmar t Phone-Embedded IMU Sensors	2015	Computing in Civil Engineering 2015	ASCE	Journal article	10.1061/9780784479247.027	Only one iteration of citation chaing was deemed necesarry
Reza, Azimi SangHyun, Lee Simaan M.AbouRizk Amin, Alvanchi	A framework for an automated and integrated project monitoring and control system for steel fabrication projects	2011	Automation in Construction	ASCE	Journal article	10.1016/j.autcon.2010.07.001	Only one iteration of citation chaing was deemed necesarry
Z.M, Deng H. Li C.M. Tam Q.P. Shen P.E.D. Love	An application of the Internet-based project management system	2001	Automation in Construction	ASCE	Journal article	10.1016/S0926-5805(99)00037-0	Only one iteration of citation chaing was deemed necesarry
Navon, R. Shpatnitsky, Y.	Field Experiments in Automated Monitoring of Road Construction	2005	Journal of Construction Engineering and Management	ASCE	Journal article	10.1061/(ASCE)0733-9364(2005)131:4(487)	Only one iteration of citation chaing was deemed necesarry
El-Omari, Samir Moselhi, Osama	Integrating automated data acquisition technologies for progress reporting of construction projects	2009	2009 26th International Symposium on Automation and Robotics in Construction	IIT Madras	Conference article	10.1016/j.autcon.2010.12.001	Only one iteration of citation chaing was deemed necesarry
Al-Jibouri, Saad H.	Monitoring systems and their effectiveness for project cost control in construction	2003	International Journal of Project Management	Elsevier Ltd	Journal article	10.1016/S0263-7863(02)00010-8	Only one iteration of citation chaing was deemed necesarry
Cheng, Tao Teizer, Jochen	Real-time data collection and visualization technol ogy in construction	2010	Research Congress 2010: Innovation for Reshaping Constructio n Practice - Proceedings of the 2010 Construction Res earch Congress	ASCE	Conference article	10.1061/41109(373)34	Only one iteration of citation chaing was deemed necesarry
Navon, R. Sacks, R.	Assessing research issues in Autom ated Project Performance Control (APPC)	2007	Automation in Construction	Elsevier B.V., Netherlands	Journal article	10.1016/j.autcon.2006.08.001	Only one iteration of citation chaing was deemed necesarry
Hildreth, John Vorster, Michael Martinez, Julio	Reduction of short-interval GPS data for construction operations analysis	2005	Journal of Construction Engineering and Management	ASCE	Journal article	10.1061/(ASCE)0733-9364(2005)131:8(920)	Only one iteration of citation chaing was deemed necesarry

Attachment 4: Stage 2 - study selection

Author(s)	Title	Year	Source	Publisher	Type document	Title score(1-6)	Key words score(1-6)	Abstract score(1-6)	General relevance (1-6)	Total score	#cited in Scopus	Peak of interest? (High-Medium-Low)	Inclusion?	Comment
From manual Search of Automation in Construction														
S. Dadhich U. Bodin U. Andersson	Key challenges in automation of earth-moving machines	2016	Automation in Construction	Elsevier	Journal article	5	5	2	1	13	1	Low	No	Focus is fully automated robotic earthmoving, not pertinent to the objectives.
Kurt M. Lundeen Suyang Dong Nicholas Fredricks Manu Akula Jongwon Seo Vineet R. Kamat	Optical marker-based end effector pose estimation for articulated excavators	2016	Automation in Construction	Elsevier	Journal article	4	6	4	3	17	4	Medium	Yes	Photobased location sensoring as a competitor to systems such as Trimble, Leica and Digpilot.
Yu Du Michael C. Dorneich Brian Steward	Virtual operator modeling method for excavator trenching	2016	Automation in Construction	Elsevier	Journal article	4	3	4	3	14	5	Medium	No	Not relevant enough
Quang Hoan Le Jae Woo Lee Soon Yong Yang	Remote control of excavator using head tracking and flexible monitoring method	2017	Automation in Construction	Elsevier	Journal article	3	3	2	2	10	0	Low	No	Remote control of excavator, not likely to contribute any relevant insights
Kurt M. Lundeen Vineet R. Kamat Carol C. Menassa Wes McGee	Scene understanding for adaptive manipulation in robotized construction work	2017	Automation in Construction	Elsevier	Journal article	3	2	2	1	8	0	Low	No	Environment pattern recognition
Mohammad Mostafa Soltani Zhenhua Zhu Amin Hammad	Skeleton estimation of excavator by detecting its parts	2017	Automation in Construction	Elsevier	Journal article	4	3	4	4	15	2	Medium	Yes	Motion tracking techniques
Hua Zhou Peng-Yu Zhao Ying-Long Chen Hua-Yong Yang	Prediction-based stochastic dynamic programming control for excavator	2017	Automation in Construction	Elsevier	Journal article	4	4	3	4	15	0	Medium	Yes	reducing fuel consumption as a product of prediction system
Hong-Chul Lee Han-Seong Gwak Jongwon Seo Dong-Eun Lee	Eco-economic excavator configuration method	2017	Automation in Construction	Elsevier	Journal article	3	5	5	4	17	0	Medium	Yes	system for choosing the right excavator
Jinwoo Kim Seokho Chi Jongwon Seo	Interaction analysis for vision-based activity identification of earthmoving excavators and dump trucks	2018	Automation in Construction	Elsevier	Journal article	No access								
Hyunsoo Kim Changbum R. Ahn David Engelhaupt SangHyun Lee	Application of dynamic time warping to the recognition of mixed equipment activities in cycle time measurement	2018	Automation in Construction	Elsevier	Journal article	3	4	5	5	17	0	Medium	Yes	Cycle time estimation based off smartphone
Jongwon Seo Seungsoo Lee Jeonghwan Kim Sung-Keun Kim	Task planner design for an automated excavation system	2011	Automation in Construction	Elsevier	Journal article	3	3	2	3	11	0	Low	No	implementing task planner to automated robotic systems
Nipesh Pradhananga Jochen Teizer	Automatic spatio-temporal analysis of construction site equipment operations using GPS data	2013	Automation in Construction	Elsevier	Journal article	5	4	6	5	20	83	High	Yes	Job site performance management by use of GPS
S. Šalinić G. Bošković, M. Nikolić	Dynamic modelling of hydraulic excavator motion using Kane's equations	2014	Automation in Construction	Elsevier	Journal article	3	3	4	3	13	11	Medium	No	Dynamic modeling of the excavator
Jungho Yoon Jeonghwan Kim Jongwon Seo Sangwook Suh	Spatial factors affecting the loading efficiency of excavators	2014	Automation in Construction	Elsevier	Journal article	4	3	3	2	12	2	Low	No	Analysis of laoding conditions
Faridaddin Vahdatikhaki Amin Hammad Hassaan Siddiqui	Optimization-based excavator pose estimation using real-time location systems	2015	Automation in Construction	Elsevier	Journal article	5	4	3	3	15	14	Medium	No	
Dongyun Wang Lijuan Zheng Hongxiang Yu Wu Zhou Liping Shao	Robotic excavator motion control using a nonlinear proportional-integral controller and cross-coupled pre-compensation	2016	Automation in Construction	Elsevier	Journal article	4	3	1	1	9	5	Low	No	Algorithm for control an automated robotic excavator
Steven J. Lorenc Leonhard E. Bernold	Excavator-mounted ordnance locating system using electromagnetic sensing technology	1998	Automation in Construction	Elsevier	Journal article	5	1	2	1	9	0	Low	No	Explotion removal ordnance for excavators
R. Navon	Research in automated measurement of project performance indicators	2007	Automation in Construction	Elsevier	Journal article	6	6	6	6	24	73	High	Yes	Higly relevant
Q.P. Ha Q.H. Nguyen D.C. Rye H.F. Durrant-Whyte	Impedance control of a hydraulically actuated robotic excavator	2000	Automation in Construction	Elsevier	Journal article	3	2	1	2	8	77	Low	No	
From literature search														#accepted from pre-work: 7/19
Esa Viljamaa Irina Peltomaa	Intensified construction process control using information integration	2013	Automation in Construction	Elsevier B.V., Netherlands	Journal article	5	4	5	5	19	10	High	Yes	Project management control by automated information gathering
Makkonen, T. Nevala, K. Heikkila, R.	A 3D model based control of an excavat	*2006*	Automation in Construction	Elsevier, Netherlands	Journal article	3	2	3	3	11	19	Low	No	
Koivo, A.J. Thoma, M. Kocaoglan, E. Andrade-Cetto, J.	Modeling and control of excavator dynamics during digging operation	1996	Journal of Aerospace Engineering	ASCE	Journal article	4	2	3	3	12	85	Low	No	Algorithm for control an automated robotic excavator
Sepehri, N. Lawrence, P.D. Sassani, F. Frenette, R.	Resolved-mode teleoperated control of heavy-duty hydraulic machines	1994	Journal of Dynamic Systems, Measurement, and Control	The American Society of Mechanical Engineers	Journal article	3	2	2	2	9	27	Low	No	Algorithm for control an automated robotic excavator
Ha, Quang Santos, Miguel Nguyen, Quang Rye, David Durrant-Whyte, Hugh	Robotic excavation in construction automation	2002	IEEE Robotics & Automation Magazine	Institute of Electrical and Electronics Engineers Inc	Journal article	3	2	2	2	9	54	Low	No	
"Plonecki, L. Trampczynski, W. Cendrowicz, J."	A concept of digital control system to assist the operator of hydraulic excavators	1998	Automation in Construction	Elsevier, Netherlands	Journal article	4	4	2	3	13	20	Low	No	Tool trajectory calculations
Jun Gu Taylor, J. Seward, D.	Modelling of an hydraulic excavator using simplified refined instrumental variable (SRIV) algorithm	2007	Journal of Control Theory and Applications		Journal article	3	2	2	2	9	2	Low	No	Non-linear algorithm
Montaser, Ali Bakry, Ibrahim Alshibani, Adel Moselhi, Osama	Estimating productivity of earthmoving operations using spatial technologies	2012	Canadian Journal of Civil Engineering	National Research Council of Can ada, Canada	Journal article	-	-	-	-	0	7	No access	No access	
Isaac, Shabtai Navon, Ronie	Can project monitoring and control be fully automated?	2014	Construction Management and Economics	Routledge	Journal article	6	5	6	6	23	5	High	Yes	Investegative article about the potential of automated control management
Singh, S.	State of the art in automation of earthmoving	1997	Journal of Aerospace Engineering	ASCE	Journal article	5	-	3	3	11	57	Medium	No	See title, a little old and is mostly concerned with total automation of machinery.
Ibrahim, Magdy Moselhi, Osama	Automated productivity assessment of earthmoving operations	2014	Electronic Journal of Information Technology in Construction	Royal Institute of |Technology, Sweden	Journal article	5	5	6	6	22	3	High	Yes	See title
Shah, Raj Kapur	A new approach for automation of location-based earthwork scheduling in road construction projects	2014	Automation in Construction	Elsevier B.V., Netherlands	Journal article	5	4	4	4	17	6	Medium	Yes	Spatial management system
Sanvido, Victor E. Medeiros, Deborah J.	Applying computer-integrated manufacturing concepts to construction	1990	Journal of Construction Engineering and Management	ASCE	Journal article	5	4	3	3	15	37	Medium	No	Not recent enoguh
Everett, John G. Slocum, Alexander H.	Automation and robotics opportunities: Construction versus manufacturing	1994	Journal of Construction Engineering and Management	ASCE	Journal article	3	4	2	3	12	23	Low	No	Too general and old
Gong, Jie Caldas, Carlos H.	An object recognition, tracking, and contextual reasoning-based video interpretation method for rapid productivity analysis of construction operations	2011	Automation in Construction	ASCE	Journal article	4	6	4	5	19	58	High	Yes	General site monitoring, migh provide useful insights.
Zhai, Dong Goodrum, Paul M. Haas, Carl T. Caldas, Carlos H.	Relationship between automation and integration of construction information systems and labor productivity	2009	Journal of Construction Engineering and Management	ASCE	Journal article	5	5	4	4	18	27	Medium	Yes	Relationship between automation of IT systems and efficiency
Qingyuan Zhu Yuanhui Liu Huosheng Hu Liang Hou Mingjie Guan	Using wavelet denoising in automatic online efficiency estimation of a hydraulic excavator	2017	Transactions of the Institute of Measurement and Control	SAGE Publicatic	Journal article	5	4	5	5	19	0	Medium	Yes	Real-time measurement of "work-speed" of excavator

Abdi, Abdollah Taghipour, Sharareh Khamooshi, Homayoun	A model to control environmental performance of project execution process based on greenhouse gas emissions using earned value management	2018	International Journal of Project Management	Elsevier Ltd	Journal article	4	3	2	3	12	0	Low	No	Not relevant enough
Memarzadeh, Milad Golparvar-Fard, Mani Niebles, Juan Carlos	Automated 2D detection of construction equipment and workers from site video streams using histograms of oriented gradients and colors	2013	Automation in Construction	Elsevier B.V., Netherlands	Journal article	4	4	5	5	18	58	High	Yes	Automated resource monitoring
Chiu, Chao-Ying Russell, Alan D.	Design of a construction management data visualization environment: A top-down approach	2011	Automation in Construction	Elsevier	Journal article	5	4	3	4	16	20	Low	No	Too general
Golparvar-Fard, Mani Bohn, Jeffrey Teizer, Jochen Savarese, Silvio Peña-Mora, Feniosky	Evaluation of image-based modeling and laser scanning accuracy for emerging automated performance monitoring techniques	2011	Automation in Construction	Elsevier B.V., Netherlands	Journal article	5	4	3	3	15	128	Low	No	Interesting, but not relevant for earthmoving operations
Cheung, Sai On Suen, Henry C.H. Cheung, Kevin K.W.	PPMS: A Web-based construction Project Performance Monitoring System	2004	Automation in Construction	Elsevier, Netherlands	Journal article	5	5	5	5	20	115	High	Yes	Interesting and quite possibly very relevant
Yang, Jun Park, Man-Woo Vela, Patricio A. Golparvar-Fard, Mani	Construction performance monitoring via still images, time-lapse photos, and video streams: Now, tomorrow, and the future	2015	Advanced Engineering Informatics	Elsevier B.V., Netherlands	Journal article	4	5	6	5	20	40	High	Yes	Overall relevance to the validity of my thesis
Vondrackova, T. Sip, M. Caha, Z.	Application of information technologies to fuel savings in construction	2015	Applied Mechanics and Materials	Trans Tech Publications, Switzerland	Journal article	4	4	3	3	14	0	Low	No	Not relevant enough
Maas, G. van Gassel, F.	The influence of automation and robotics on the	2005	Automation in Construction	Elsevier, Netherlands	Journal article	4	4	4	4	16	11	Medium	Yes	Overall relevance to the validity of my thesis
Dimitrov, A. Golparvar-Fard, M.	Vision-based material recognition for automated monitoring of construction progress and generating building information modeling from unordered site image collections	2014	Advanced Engineering Informatics	Elsevier B.V., Netherlands	Journal article	3	2	3	3	11	0	Low	No	Detailed system for photo recognition, not really relevant
Louis, J. Dunston, P.S.	Methodology for real-time monitoring of construction operat ions using finite state machines and discrete-event operation models	2017	Journal of Construction Engineering and Management	ASCE	Journal article	4	4	4	4	16	0	Medium	Yes	See ttile
From backwards citation chaining														#accepted from literature search: 12/27
Salmasi, Farzad Rajaei	Control strategies for hybrid electric ve hicles: Evolution, classification, comparison, and futuretrends	2007	IEEE Transactions on Vehicular Technology	Institute of Electrical and Electronics	Journal article	4	4	4	4	16	338(IEEE)	High	Yes	Might prove usefull
DAVID J. EDWARDS GARY D. HOLT	a model for calculating excavator productivity and output costs	2000	Engineering, Construction and Architectural Management	MCB UP Ltd	Journal article	No access	No access	No access	No access		No access	No access	No access	No access
Junli, Yanga David, Jedwardsa Peter E.D, Love	A computational intelligent fuzzy model approach for excavator cycle time simulation	2003	Automation in Construction		Journal article	5	4	4	4	17	11	Medium	Yes	see title
Azar, E.R. Dickinson, S. McCabe, B.	Server-Customer Interaction Tracker: Comput er Vision-Based System to Estimate Dirt-LoadingCycles	2013	Journal of Construction Engineering & Management	American Society of Civil Engineers, USA	Journal article	4	4	5	4	17	-	Medium	Yes	Cycle time estimation based off photo pattern recognition
Kannan, Govindan	Field studies in construction equipment economics and productivity	2011	Journal of Construction Engineering and Management	ASCE	Journal article	4	5	5	5	19	11	High	Yes	Promising
Navon, R.	Automated project performance control of construction projects	2005	Automation in Construction	ASCE	Journal article	5	4	4	4	17	98	High	Yes	
Ahn, C.R. SangHyun Lee Pena-Mora, F.	Application of Low-Cost Accelerometers for Measuring the Operational Efficiency of a Construction Equipment Fleet	2015	Journal of Computing in Civil Engineering	ASCE	Journal article	4	4	4	4	16	7	Medium	Yes	Alt fuel consumption measurements
Mathur, N. Aria, S.S. Adams, T. Ahn, C.R. Lee, S.	Automated Cycle Time Measurement and Analysis of Excavato r's Loading Operation UsingSmart Phon e-Embedded IMU Sensors	2015	Computing in Civil Engineering 2015	ASCE	Journal article	3	2	3	3	11	-	Medium	Yes	See title
Reza, Azimi SangHyun, Lee Simaan M.AbouRizk Amin, Alvanchi	A framework for an automated and integrated project monitoring and control system for steel fabrication projects	2011	Automation in Construction	ASCE	Journal article	4	4	3	4	15	34	Medium	Yes	very general, but might prove hepful
Z.M, Deng H. Li C.M. Tam Q.P. Shen P.E.D. Love	An application of the Internet-based project management system	2001	Automation in Construction	ASCE	Journal article	5	3	3	3	14	97	Medium	No	old not that relevant upon further reading
Navon, R. Shpatnitsky, Y.	Field Experiments in Automated Monitoring of Road Construction	2005	Journal of Construction Engineering and Management	ASCE	Journal article	4	4	3	4	15	52	High	Yes	nice
El-Omari, Samir Moselhi, Osama	Integrating automated data acquisition technologies for progress reporting of construction projects	2009	2009 26th International Symposium on Automation and Robotics in Construction	IIT Madras	Conference article	4	4	4	4	16	53	Medium	Yes	
Al-Jibouri, Saad H.	Monitoring systems and their effectiveness for project cost control in construction	2003	International Journal of Project Management	Elsevier Ltd	Journal article	4	3	2	3	12	49	Low	No	
Cheng, Tao Teizer, Jochen	Real-time data collection and visualization technology i n construction	2010	Research Congress 2010: Innovation for Reshaping Construction Practic e - Proceedings of the 2010 Construction Research Congress	ASCE	Conference article	4	4	4	4	16	10	Medium	Yes	might prove usefull to the overall validity of my thesis
Navon, R. Sacks, R.	Assessing research issues in Automate d Project Performance Control (APPC)	2007	Automation in Construction		Journal article	4	4	5	5	18	107	High	Yes	Overall relevance to the validity of my thesis
Hildreth, John Vorster, Michael Martinez, Julio	Reduction of short-interval GPS data for construction operations analysis	2005	Journal of Construction Engineering and Management	ASCE	Journal article	5	4	5	5	19	37	High	Yes	
														#accepted from backwards citation chaining:13/27
													#articles total:	32

Attachment 5: Stage 3 - Charting the data, final pool

Author(s)	Title	Year	Source	Publisher	Type document
From manual Search of Automation in Construction					
Kurt M. Lundeen Suyang Dong Nicholas Fredricks Manu Akula Jongwon Seo Vineet R. Kamat	Optical marker-based end effector pose estimation for articulated excavators	2016	Automation in Construction	Elsevier	Journal article
Mohammad Mostafa Soltani Zhenhua Zhu Amin Hammad	Skeleton estimation of excavator by detecting its parts	2017	Automation in Construction	Elsevier	Journal article
Hua Zhou Peng-Yu Zhao Ying-Long Chen Hua-Yong Yang	Prediction-based stochastic dynamic programming control for excavator	2017	Automation in Construction	Elsevier	Journal article
Hong-Chul Lee Han-Seong Gwak Jongwon Seo Dong-Eun Lee	Eco-economic excavator configuration method	2017	Automation in Construction	Elsevier	Journal article
Hyunsoo Kim Changbum R. Ahn David Engelhaupt SangHyun Lee	Application of dynamic time warping to the recognition of mixed equipment activities in cycle time measurement	2018	Automation in Construction	Elsevier	Journal article
Nipesh Pradhananga Jochen Teizer	Automatic spatio-temporal analysis of construction site equipment operations using GPS data	2013	Automation in Construction	Elsevier	Journal article
R. Navon	Research in automated measurement of project performance indicators	2007	Automation in Construction	Elsevier	Journal article
From literature search					
Esa Viljamaa Irina Peltomaa	Intensified construction process control using information integration	2013	Automation in Construction	Elsevier B.V., Netherlands	Journal article
Isaac, Shabtai Navon, Ronie	Can project monitoring and control be fully automated?	2014	Construction Management and Economics	Routledge	Journal article
Ibrahim, Magdy Moselhi, Osama	Automated productivity assessment of earthmoving operations	2014	Electronic Journal of Information Technology in Construction	Royal Institute of |Technology, Sweden	Journal article
Shah, Raj Kapur	A new approach for automation of location-based earthwork scheduling in road construction projects	2014	Automation in Construction	Elsevier B.V., Netherlands	Journal article
Gong, Jie Caldas, Carlos H.	An object recognition, tracking, and contextual reasoning-based video interpretation method for rapid productivity analysis of construction operations	2011	Automation in Construction	ASCE	Journal article
Zhai, Dong Goodrum, Paul M. Haas, Carl T. Caldas, Carlos H.	Relationship between automation and integration of construction information systems and labor productivity	2009	Journal of Construction Engineering and Management	ASCE	Journal article
Qingyuan Zhu Yuanhui Liu Huosheng Hu Liang Hou Mingjie Guan	Using wavelet denoising in automatic online efficiency estimation of a hydraulic excavator	2017	Transactions of the Institute of Measurement and Control	SAGE Publications, UK	Journal article
Memarzadeh, Milad Golparvar-Fard, Mani Niebles, Juan Carlos	Automated 2D detection of construction equipment and workers from site video streams using histograms of oriented gradients and colors	2013	Automation in Construction	Elsevier B.V., Netherlands	Journal article
Cheung, Sai On Suen, Henry C.H. Cheung, Kevin K.W.	PPMS: A Web-based construction Project Performance Monitoring System	2004	Automation in Construction	Elsevier, Netherlands	Journal article
Yang, Jun Park, Man-Woo Vela, Patricio A.	Construction performance monitoring via still images, time-lapse photos, and video streams: Now, tomorrow, and the future	2015	Advanced Engineering Informatics	Elsevier B.V., Netherlands	Journal article
Maas, G. van Gassel, F.	The influence of automation and robotics on the performance construction	2005	Automation in Construction	Elsevier, Netherlands	Journal article
Louis, J. Dunston, P.S.	Methodology for real-time monitoring of construction operations using finite state machines and discrete-event operation models	2017	Journal of Construction Engineering and Management	ASCE	Journal article
From backwards citation chaining					
Salmasi, Farzad Rajaei	Control strategies for hybrid electric vehicles : Evolution, classification, comparison, and futuretrends	2007	IEEE Transactions on Vehicular Technology	Institute of Electrical and Electronics Engineers Inc	Journal article
Junli, Yanga David, Jedwardsa Peter E.D, Love	A computational intelligent fuzzy model approach for excavator cycle time simulation	2003	Automation in Construction		Journal article

Azar, E.R. Dickinson, S. McCabe, B.	Server- Customer Interaction Tracker: Computer Visi on-Based System to Estimate Dirt- LoadingCycles	2013	Journal of Construction Engineering & Management	American Society of Civil Engineers, USA	Journal article
Kannan, Govindan	Field studies in construction equipment economics and productivity	2011	Journal of Construction Engineering and Management	ASCE	Journal article
Navon, R.	Automated project performance control of construction projects	2005	Automation in Construction	ASCE	Journal article
Ahn, C.R. SangHyun Lee Pena-Mora, F.	Application of Low-Cost Accelerometers for Measuring the Operational Efficiency of a Construction Equipment Fleet	2015	Journal of Computing in Civil Engineering	ASCE	Journal article
Mathur, N. Aria, S.S. Adams, T. Ahn, C.R. Lee, S.	Automated Cycle Time Measurement and Analysis of Excavator's Lo ading Operation UsingSmart Phone- Embedded IMU Sensors	2015	Computing in Civil Engineering 2015	ASCE	Journal article
Reza, Azimi SangHyun, Lee Simaan M.AbouRizk Amin, Alvanchi	A framework for an automated and integrated project monitoring and control system for steel fabrication projects	2011	Automation in Construction	ASCE	Journal article
Navon, R. Shpatnitsky, Y.	Field Experiments in Automated Monitoring of Road Construction	2005	Journal of Construction Engineering and Management	ASCE	Journal article
El-Omari, Samir Moselhi, Osama	Integrating automated data acquisition technologies for progress reporting of construction projects	2009	2009 26th International Symposium on Automation and Robotics in Construction	IIT Madras	Conference article
Cheng, Tao Teizer, Jochen	Real-time data collection and visualization technology in co nstruction	2010	Innovation for Reshaping Construction Practic e - Proceedings of the	ASCE	Conference article
Navon, R. Sacks, R.	Assessing research issues in Automated Proj ect Performance Control (APPC)	2007	Automation in Construction		Journal article
Hildreth, John Vorster, Michael Martinez, Julio	Reduction of short-interval GPS data for construction operations analysis	2005	Journal of Construction Engineering and Management	ASCE	Journal article
				#articles total:	32

Attachment 6: Stage 3 - COAS-Evaluation

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
Optical marker-based end effector pose estimation for articulated excavators (4)	Lundeen, Kurt M. Dong, Suyan Fredricks, Nicholas Akula, Manu Seo, Jongwon Kamat, Vineet R.	2016	Automation in Construction, Elsevier	Journal article	Manual pre-work search - Automation in Construction	"Marker-based pose estimation, in which optical cameras monitor fiducial markers to determine the threedimensional positioning and orientation of an articulated machine's end effector, has been identified as a potential low-cost alternative to currently available machine control and guidance systems"

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Kurt M. Lundeen: Doctoral Student, University of Michigan Suyang Dong: University of Michigan Jongwon Seo: Hanyang University (Seoul, South Korea) Vineet R. Kamat: Professor of Civil Engineering, University of Michigan Nicholas Fredricks: University of Michigan Manu Akula: University of Michigan Credible Publisher	3: Top-tier
Objectivity	3	Multiple authors, conclusions based of several physical experiments	
Accuracy	3	Well documented and explained methodology, experiments on a new tech	
Suitability	2	A different tech to pose estimation and machine guidance. Might prove usefull when discussing the alternatives but not pertinent to the main objectives.	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; publisher	Type document	Acquisition	Scope/goal
Skeleton estimation of excavator by detecting its parts (2)	Mohammad Mostafa Soltani Zhenhua Zhu Amin Hammad	2017	Automation in Construction, Elsevier	Journal article	Manual pre-work search - Automation in Construction	"This paper mainly focuses on determining the 2D skeleton of excavators based on the videos received from the cameras available on the site. The method takes advantage of synthetic images of each excavator's part to train the parts' detectors."

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Soltani, M.M: PhD, Concordia University, Canada Zhenhua Zhu: Concordia University, Canada Hammad, A: Professor at CIISE, Concordia University, Canada Credible Publisher	3: Top-tier
Objectivity	3	Credible authors, considered objective	
Accuracy	3	Comprehensive literature study, well explained	
Suitability	2	Pose and skeleton recognition of excavators in real-time. Might be useful in discussing the result of the thesis in comparison to alternatives	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source	Type document	Acquisition	Scope/goal
Prediction-based stochastic dynamic programming control for excavator (0)	Hua Zhou Peng-Yu Zhao Ying-Long Chen Hua-Yong Yang	2017	Automation in Construction, Elsevier	Journal article	Manual pre-work search - Automation in Construction	"Because the fuel efficiency of excavators is low and the energy loss is considerable, a prediction-based stochastic dynamic programming (PBSDP) control strategy is proposed in this study to reduce the energy and fuel consumptions. Using the torque prediction method, the optimization control strategy can be used in real time to improve the fuel efficiency."

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Hua Zhou: State Key Laboratory of Fluid Power and Mechatronic Systems, Zhejiang University, Hangzhou Peng-Yu Zhao: State Key Laboratory of Fluid Power and Mechatronic Systems, Zhejiang University, Hangzhou Ying-Long Chen: State Key Laboratory of Fluid Power and Mechatronic Systems, Zhejiang University, Hangzhou Hua-Yong Yang: State Key Laboratory of Fluid Power and Mechatronic Systems, Zhejiang University, Hangzhou Credible publisher	3: Top-tier
Objectivity	3	Evaluated to be objective, clearly states the papers limitations and achievements in objective terms	
Accuracy	2	Based off of simulated results, real experiments/testing not provided	
Suitability	3	Certain parameters needed for fuel saving might prove useful arguing the automated collection of such data	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal

Eco-economic excavator configuration method (0)	Lee, Hong-Chul Gwak, Han-Seong Seo, Jongwon Lee, Dong-Eun	2017	Automation in Construction, Elsevier	Journal article	Manual pre-work search - Automation in Construction	"This paper presents a computational method called the Eco-Economic Excavator Configuration (E3C), which selects the most favorable configuration of a heavy duty excavator according to the earthwork package and its job conditions."

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Lee, Hong-Chul: KyungPook National University, School of Architecture and Civil Engineering Gwak, Han-Seong: KyungPook National University, School of Architecture and Civil Engineering Seo, Jongwon: Hanyang University, Dept. of Civil and Environmental Engrg Lee, Dong-Eun: Hanyang University, Dept. of Civil and Environmental Engrg Credible publisher	3: Top-tier
Objectivity	3	Multiple credible authors, considered objective	
Accuracy	3	Considered higly accurate	
Suitability	3	Very suitable, presents E3C, whic is a system for estimating the best suited excavator for the job using several parameters a performance monitoring system might provide. This connection is considered relevant to the objective of the thesis.	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
Application of dynamic time warping to the recognition of mixed equipment activities in cycle time measurement (0)	Hyunsoo, Kim Ahn, Changbum R. Engelhaupt, David Lee, SangHyun	2018	Automation in Construction, Elsevier	Journal article	Manual pre-work search - Automation in Construction	"..this study explores the feasibility of measuring cycle times of construction equipment using embedded IMU sensors in a smartphone."

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Hyunsoo, Kim: Dept. of Architectural Engineering, Gyeongnam National University of Science and Technology Ahn, Changbum R: Department of Construction Science, Texas A&M University Engelhaupt, David: Dept. of Civil Engineering, University of Nebraska–Lincoln Lee, SangHyun: Dept. of Civil and Environmental Engineering, Univ. of Michigan Credible publisher	3: Top-tier
Objectivity	3	Considered objective	
Accuracy	3	Experiments performed on a singular model of excavator, the principle seems to be transferable to other machine aswell. New data	
Suitability	3	Considered relevant, presents a cost efficient method of measuring cycle times, with fairly high accuracy, on excavators.	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
Automatic spatio-temporal analysis of construction site equipment operations using GPS data (83)	Pradhananga, Nipesh Teizer, Jochen	2013	Automation in Construction, Elsevier	Journal article	Manual pre-work search - Automation in Construction	"This paper presents technology and algorithms that have the potential in aiding the automated assessment of construction site equipment operations. Utilizing commercially available low-cost global positioning system (GPS) devices enables the continuous data logging of equipment location in addition to simultaneously recording timestamps."

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Pradhananga, Nipesh: School of Civil and Environmental Engineering, Georgia Institute of Technology Teizer, Jochen: Educator, Researcher and Consultant Credible publisher	3: Top-tier
Objectivity	3	Credible authors, considered objective. Also high number citations conveys objectivity and credibility.	
Accuracy	2	GPS accuracy tested on a very limited area. Considered sufficiently accurate nonetheless	
Suitability	3	Suitable for the validity of the thesis, also presents some of the possible benefits of GPS tracking that might prove usefull in combination with performance monitoring systems.	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
Research in automated measurement of project performance indicators (73)	Navon, R.	2007	Automation in Construction, Elsevier	Journal article	Manual pre-work search - Automation in Construction	"The purpose of the research presented in this paper is to improve monitoring and control information, i.e. to offer it on a daily basis, to improve its quality and integrity and to reduce the cost of generating it. To do all this, the Technion APPC researchers started exploring the use of automated data collection (ADC) technologies."

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Navon, R: Construction Automation Laboratory–Faculty of Civil and Environmental Engineering, Technion City Credible publisher	

Objectivity	3	Single Author, however well documented statements, and objective reasoning. Considered objective.	3: Top-tier
Accuracy	2	Literature study, theoretical outline of ADC model is well reasoned.	
Suitability	3	Lots of great insight into automated information gathering.	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
Intensified construction process control using information integration (10)	Viljamaa, E. Peltomaa, I.	2013	Automation in Construction, Elsevier B.V., Netherlands	Journal article	Literature search - Compendex EI	"The objective of this research was to improve process management through more effective information integration, processing, and exploitation, leading to an intensified infrastructure building process with more effective process control and reaction to process status changes."

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Viljamaa, E.: VTT Technical Research Centre of Finland Peltomaa, I.: VTT Technical Research Centre of Finland Credible publisher	3: Top-tier
Objectivity	3	Considered objectiven, no bias identified.	
Accuracy	3	State-of-the-art review, field studies,personell interview. Considered accurate.	
Suitability	3	Several interessting arguments surrounding the general use of data collection methods. Considered suitable	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
Can project monitoring and control be fully automated? (5)	Isaac, S. Navon, R.	2014	Construction Management and Economics; Routledge	Journal article	Literature search - Compendex EI	"A framework for semi-automated project monitoring and control is proposed, in which both manually and automatically collected data can be incorporated."

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Isaac, S.: Department of Structural Engineering, Ben Gurion University of the Negev Navon, R: Construction Automation Laboratory–Faculty of Civil and Environmental Engineering, Technion City Credible publisher	3: Top-tier
Objectivity	3	Considered objective.	
Accuracy	2	Theoretical outline of the APPC model based off of "decades of studies", well documented. Considered accurate.	
Suitability	3	A general model for performance monitoring and project control(APPC). Considered suitable.	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
Automated productivity assessment of earthmoving operations (3)	Ibrahim, Magdy Moselhi, Osama	2014	Electronic Journal of Information Technology in Construction; Royal Institute of Technology, Sweden	Journal Article	Literature search - Compendex EI	"This paper presents an automated system for actual productivity assessment of earthmoving operations in near real-time. Several research attempts had been made to calculate productivity, but a number limitations had been found in literature such as, assuming the hauling unit is loaded to its full capacity and the need for manual user entry of efficiency factors (For example: bucket fill factor)."

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Ibrahim, Magdy: PhD Candidate, P.Eng, Concordia University Moselhi, Osama: Professor, Concordia University Credible publisher	3: Top-tier
Objectivity	3	Considered objective	
Accuracy	3	8 experiments was done on real site conditions, considered accurate.	
Suitability	3	The article establishes a system for automated data collection on earthmoving operations. Considered pertinent to comparisons.	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
A new approach for automation of location-based earthwork scheduling in road construction projects (6)	Shah, Raj Kapur	2014	Automation in Construction; Elsevier B.V., Netherlands	Journal Article	Literature search - Compendex EI	"....a prototype computer-based model was developed using the theory of the location-based planning. An arithmetic algorithm was designed by incorporating road design data, sectional quantities, variable productivity rates and haulage distance"

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Shah, R.K: Faculty of Technology and Environment, Liverpool John Moores University, Credible publisher	3: Top-tier
Objectivity	3	The article is considered objective	
Accuracy	3	Well documented literature study, case studies as proof of concept. Considered accurate	
Suitability	2	Considered sufficiently relevant whith regards to pinpointing different strategies.	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
An object recognition, tracking, and contextual reasoning-based video interpretation method for rapid productivity analysis of construction operations (58)	Gong, Jie Caldas, Carlos H.	2011	Automation in Construction; Elsevier B.V., Netherlands	Journal Article	Literature search - Compendex EI	"This paper proposed and described the elements, processes, and algorithms that comprise a computational and intelligent construction video interpretation method"

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Jie Gong: Dept. of Construction, Southern Illinois University Edwardsville Caldas, Carlos H.: Dept. of Civil, Architectural & Environmental Engineering, University of Texas at Austin Credible publisher	3: Top-tier
Objectivity	3	Content consistent with existing research. Considered objective	
Accuracy	3	4 case studies of actual site conditions. Considered accurate	
Suitability	2	Video system for measuring prodcutivity on all kinds of activities on site, somewhat suitable.	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
Relationship between automation and integration of construction information systems and labor productivity (27)	Zhai, Dong Goodrum, Paul M. Haas, Carl T. Caldas, Carlos H.	2009	Journal of Construction Engineering and Management; ASCE	Journal Article	Literature search - Compendex EI	"An opportunity to examine new evidence exists with the emergence of the Construction Industry Institute's Benchmarking and Metrics database on construction productivity and practices. This article presents an analysis of that data to determine if there is a relationship between labor productivity and level of IT implementation and integration."

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Zhai, Dong: Graduate Research Assistant, Dept. of Civil Engineering, Univ. Of Kentucky, Lexington Goodrum, Paul M.:Associate Professor, Dept. of Civil Engineering, 151C Raymond Bldg., Univ. of Kentucky, Lexington Haas, Carl T. : Professor, Dept. of Civil Engineering, Univ. of Waterloo, Waterloo, Ontario, Canada Caldas, Carlos H.: Assistant Professor, Dept. of Civil, Architectural and Environmental, Austin, TX Highly credible publisher	3: Top-tier
Objectivity	3	Counter-arguments are explored. Considered objective	
Accuracy	2	Somewhat lack of existing research to confirm the data. Howerever the methodology is considered strong and the results are plausible.	
Suitability	3	Statistical analysis of the releationship between productivity and automated data collection. Considered suitable.	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
Using wavelet denoising in automatic online efficiency estimation of a hydraulic excavator (0)	Qingyuan Zhu Yuanhui Liu Huosheng Hu Liang Hou Mingjie Guan	2017	Transactions of the Institute of Measure ment and Control; SAGE Publications, UK	Journal Article	Literature search - Compendex EI	"This paper proposes an online and low-cost detection method to estimate the operating speed based on the peak detection of the main pump outlet pressure."

COAS - Evaluation

Criteria	Score	Justification	Final score

Credibility	3	Qingyuan Zhu:Department of Mechanical and Electrical Engineering, Xiamen University, Xiamen, Fujian, China Yuanhui Liu: Department of Mechanical and Electrical Engineering, Xiamen University, Xiamen, Fujian, China Huosheng Hu: School of Computer Science & Electronic Engineering, University of Essex, Colchester Liang Hou:Department of Mechanical and Electrical Engineering, Xiamen University, Xiamen, Fujian, China Mingjie Guan: Department of Mechanical and Electrical Engineering, Xiamen University, Xiamen, Fujian, China Credible publisher	3: Top-tier
Objectivity	3	Considered objective	
Accuracy	3	510 groups of data. Considered accurate	
Suitability	3	System for noise exclusion when measuring excevator operations, Considered suitable.	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
Automated 2D detection of construction equipment and workers from site video streams using histograms of oriented gradients and colors (58)	Memarzadeh, Milad Golparvar-Fard, Mani Niebles, Juan Carlos	2013	Automation in Construction; Elsevier B.V., Netherlands	Journal article	Literature search - Compendex EI	"This paper presents a computer vision based algorithm for automated 2D detection of construction workers and equipment from site video streams. The state-of-the-art research proposes semi-automated detection methods for tracking of construction workers and equipment."

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Memarzadeh, Milad: Vecellio Construction Engineering and Management, Virginia Tech, Blacksburg Golparvar-Fard, Mani: Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign Niebles, Juan Carlos: c Electrical and Electronic Engineering, Universidad del Norte, Colombia Credible publisher	3: Top-tier
Objectivity	3	Considered objective	
Accuracy	3	300 h of video streams were recorded from five different construction projects Considered accurate	
Suitability	3	Robust and flexible system for object recognition trhough 2d video feed. Considered suitable.	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
PPMS: A Web-based construction Project Performance Monitoring System (115)	Cheung, Sai On Suen, Henry C.H. Cheung, Kevin K.W.	2004	Automation in Construction; Elsevier B.V., Netherlands	Journal article	Literature search - Compendex EI	"This paper describes the development of a Web-based construction Project Performance Monitoring System (PPMS) that aims to assist project managers in exercising construction project control."

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Cheung, Sai On: City University of Hong Kong, Kowloon, Hong Kong Suen, Henry C.H.: City University of Hong Kong, Department of Building and Construction, Kowloon, Hong Kong Cheung, Kevin K.W.: Macquarie University, Department of Environmental Sciences, Sydney, Australia Credible publisher	3: Top-tier
Objectivity	3	Considered objective	
Accuracy	3	The methodology and theory is very well explained. Considered accurate	
Suitability	3	General purpose system for overal project effiency calculations Considered suitable.	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
Construction performance monitoring via still images, time-lapse photos, and video streams: Now, tomorrow, and the future (40)	Yang, Jun Park, Man-Woo Vela, Patricio A. Golparvar-Fard, Mani	2015	Advanced Engineering Informatics; Elsevier	Journal article	Literature search - Compendex EI	"...this paper extensively reviews these stateof-the-art vision-based construction performance monitoring methods. Based on the level of information perceived and the types of output, these methods are mainly divided into two categories (namely project level: visual monitoring of civil infrastructure or building elements vs. operation level: visual monitoring of construction equipment and workers)."

COAS - Evaluation

Criteria	Score	Justification	Final score

Credibility	3	Yang, Jun: School of Mechanics, Civil Engineering and Architecture, Northwestern Polytechnical University, China Park, Man-Woo: Department of Civil and Environmental Engineering, Myongji University, South Korea Vela, Patricio A.: School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA, United States Golparvar-Fard, M.:Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana Credible publisher	3: Top-tier
Objectivity	3	Credible authors, also high number citations conveys objectivity and credibility. Considered objective	
Accuracy	3	The methodology and theory is very well explained and comprehensive. Considered accurate	
Suitability	3	An exploration of the challanges that presents themselves to the performance monitoring business in construction. Considered suitable.	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
The influence of automation and robotics on the performance construction (11)	Maas, G. van Gassel, F.	2005	Automation in Construction; Elsevier B.V., Netherlands	Journal article	Literature search - Compendex EI	"This focuses on performance management, construction engineering and construction management. New developments being discussed in this field are new design strategies, human machine technologies, employee safety, progress monitoring, distributed production information and Personal Digital Assistants (PDAs)."

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Maas, G.: Technische Universiteit Eindhoven, Eindhoven, Netherlands van Gassel, F.: Technische Universiteit Eindhoven, Eindhoven, Netherlands Credible publisher	2: Acceptable
Objectivity	2	Credible authors, Although somewhat unreasoned statements with no scientific evidence are made . Considered sufficiently objective nevertheless.	
Accuracy	2	somewhat unclear methodology. Considered sufficiently accurate.	
Suitability	2	A close evaluation of automation influnce on construction. Considered suitable.	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
Methodology for real-time monitoring of constructio n operations using finite state machines and discrete-event operation models (0)	Louis, J. Dunston, P.S.	2017	Journal of Construction Engineering and Management; ASCE	Journal article	Literature search - Compendex EI	"This paper provides a methodology that enables the real-time monitoring of construction operations by synthesizing sensor data through the consideration of resources as finite-state machines that provide real-time input to a context-rich operation model that codifies the construction process. "

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Louis, J.: Ph.D. Candidate, Lyles School of Civil Engineering, Purdue Univ., West Lafayette Dunston, P.S.: Professor, Lyles School of Civil Engineering, Purdue Univ., West Lafayette Credible publisher	3: Top-tier
Objectivity	3	Credible authors. Considered objective	
Accuracy	2	Well explained, although the implications of some of the statements are hard to fully evaluate. Considered suffieciently accurate.	
Suitability	3	Finite state machines are certainly relevant. Considered suitable	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
Control strategies for hybrid el ectric vehicles: Evolution, classification, comparison, and futuretrends 338(IEEE)	Salmasi, Farzad Rajaei	2007	Vehicular Technology; Institute of Electrical and Electronics Engineers Inc	Journal article	Backwards citation chaining	"This paper classifies and extensively overviews the state-of-the-art control strategies for HEVs."

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Salmasi, Farzad Rajaei: Ph.D. Texas A&M University, College Station Credible publisher, singular author	2: Acceptable
Objectivity	3	Credible author. Altough the article is the work of a singular author, decent amount of citations in Scopus is evidence of objectivity and credibility. Also no alterior motives detected i article. Considered objective	
Accuracy	3	Suffieciently documented. Theory is thoroughly explained and argued. Considered accurate.	
Suitability	1	low score on suitability, has some referencable statements which is why it is allowed to reach the status "acceptable". Considered suitable.	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
A computational intelligent fuzzy model approach for excavator cycle time simulation (13)	Yanga, J. Edwardsa, D.J. Love, P.E.D.:	2003	Automation in construction; Elsevier, Netherlands	Journal article	Backwards citation chaining	"...this paper presents a computational intelligent 'fuzzy' model with the ability to forecast excavator cycle time. "

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Yanga, J.: Department of Civil and Building Engineering, Off-highway Plant and Equipment Research Centre (OPERC) Edwardsa, D.J.: Department of Civil and Building Engineering, Off-highway Plant and Equipment Research Centre (OPERC) Love, P.E.D.: We-B Centre, School of Management Information Systems, Edith Cowan University Credible publisher.	3: Top-tier
Objectivity	3	Considered objective	
Accuracy	2	"The developed model is based upon 70 separate cycle time observations obtained from four plant manufacturers." Considered accurate.	
Suitability	3	Prediction model for excavator cycle times. Considered suitable	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
Server Customer Interaction Tracker Computer Vision-Based System to Estimate Dirt-LoadingCycles (-)	Azar, E.R. Dickinson, S. McCabe, B.	2013	Journal of Construction Engineering & Management; ASCE	Journal article	Backwards citation chaining	"In this research, we introduce a vision-based framework, named SCIT, which can recognize and estimate dirt loading cycles. "

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Azar, E.R.: Ph.D. Candidate, Dept. of Civil Engineering, Univ. of Toronto, Dickinson, S.: Professor, Dept. of Computer Science, Univ. of Toronto McCabe, B.: Associate Professor, Dept. of Civil Engineering, Univ. of Toronto Credible publisher.	3: Top-tier
Objectivity	3	Credible authors. Upon reading, no signs of alterior motives. Considered objective	
Accuracy	2	Some of the introductory assumption are not supported by evidence and it certainly seems possible that these statements are not sufficiently explored. However given the need for a visonbased system, the methodology holds ground. Considered acceptable.	
Suitability	3	Object recognition using photo and algorithms. Considered suitable.	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
Field Studies in Construction Equipment Economics and Productivity (10)	Kannan, Govindan	2011	Journal of construction engineering and management; ASCE	Journal article	Backwards citation chaining	"....the purpose of this paper is twofold: (a) to evaluate the performance of the tools from the body of knowledge, and (b) to record observations and knowledge with a hope that they can serve as seeds for new research"

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Kannan, Govindan: Vice President of Business Development, Volvo Group North America Credible publisher, credibility checked author	2: Acceptable
Objectivity	2	Somewhat based subjective reasoning, this is clearly declared however. Considered objective.	
Accuracy	2	Some statements are subjective and not based in verifieable evidence. Considered acceptable due to the statements being in line with common sense and the overall reasearch field.	
Suitability	3	Some potentially usefull insights. Considered suitable	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
Automated project performance control of construction projects(98)	Navon, R.	2005	Automation in Construction; ASCE	Journal article	Backwards citation chaining	"The paper reviews the state of the art in this field, describing how automated data collection (ADC) enhances realtime construction data to be collected—so far, mainly in the area of earthmoving operations"

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Navon, R: Construction Automation Laboratory–Faculty of Civil and Environmental Engineering, Technion City Credible publisher.	3: Top-tier
Objectivity	3	Reemergent author in this field of research. Considered objective	
Accuracy	3	Claims are substantiated by several sources. Considered sufficiently accurate.	

Suitability	3	State-of-the-art field study of ADCs. Considered suitable.	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
Application of Low-Cost Accelerometers for Measuring the Operational Efficiency of a Construction Equipment Fleet (7)	Ahn, C.R. SangHyun Lee Pena-Mora, F.	2015	Journal of Computing in Civil Engineering; ASCE	Journal article	Backwards citation chaining	"...this paper examines the feasibility of measuring the operational efficiency of equipment using low-cost accelerometers."

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Ahn, C.R.: Assistant Professor, Univ. of Nebraska-Lincoln SangHyun Lee: Assistant Professor, Dept. of Civil and Environmental Engineering, Univ. of Michigan Pena-Mora, F.: Professor of Earth and Environmental Engineering and of Computer Science, Columbia Univ. Credible publisher, credibility checked authors	3: Top-tier
Objectivity	3	Credible authors. Considered objective.	
Accuracy	3	Several experiments performed to obtain a considerable amount of data to analyse. Considered sufficiently accurate.	
Suitability	3	Considered suitable.	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
Automated Cycle Time Measurement and Analysis of Excavator's Loading Operation Using Smart Phone-Embedded IMU Sensors(0)	Mathur, N. Aria, S.S. Adams, T. Ahn, C.R. Lee, S.	2015	Computing in Civil Engineering 2015. International Workshop on Computing in Civil Engineering. Proceedings; ASCE	Conference proceedings	Backwards citation chaining	" we aim to develop a non-invasive technique of using a smart phone to measure the various activity modes (e.g. wheel base motion, cabin rotation and arm movement for excavator) and subsequently duty cycle of construction equipment."

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Mathur, N.: Department of Civil andEnvironmental Engineering, University of Michigan Aria, S.S.: Charles Durham School of Architectural Engineering and Construction, University of Nebraska Adams, T.: Charles Durham School of Architectural Engineering and Construction, University of Nebraska Ahn, C.R.: Assistant Professor, Charles Durham School of Architectural Engineering and Construction, University of Nebraska Lee, S.: Associate Professor, Department of Civil and Environmental Engineering, University of Michigan Credible publisher, credibility checked authors	3: Top-tier
Objectivity	3	Clearly states the limitations that this research is exposed to. Considered objective.	
Accuracy	3	The scope of the article is quite specific and the limitations to the degree of fullfilment are also stated. Considered sufficiently accurate.	
Suitability	3	Considered suitable.	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
A framework for an automated and integrated project monitoring and control system for steel fabrication projects (34)	Azimi, R. SangHyun Lee AbouRizk, S.M. Alvanchi, A.	2011	Automation in Construction; Elsevier Science	Journal article	Backwards citation chaining	"This paper presents an automated and integrated project monitoring and control framework that facilitates decision making by enabling project managers to take corrective actions immediately after deviations occur and to mitigate potential damage to ongoing steel fabrication project"

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Azimi, R.: Department of Civil and Environmental Engineering, University of Alberta, Edmonton SangHyun Lee: Department of Civil and Environmental Engineering, University of Michigan AbouRizk, S.M.: Department of Civil and Environmental Engineering, University of Alberta, Edmonton Alvanchi, A.: Department of Civil and Environmental Engineering, University of Alberta, Edmonton Credible publisher, credibility checked authors	3: Top-tier
Objectivity	3	Credible authors, claims are substantiated. Considered objective.	
Accuracy	2	Theory is explained well. Considered accurate.	
Suitability	3	Relevant in the sense of capturing some fundemental monitoring concepts. Good for comparisons with other parts of the construction industry. Considered suitable.	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
Field Experiments in Automated Monitoring of Road Construction (52)	Navon, R. Shpatnitsky, Y.	2005	Journal of Construction Engineering and Management; ASCE	Journal article	Backwards citation chaining	"The present paper describes the development of a real-time monitoring model capable of measuring productivity and progress automatically."

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Navon, R.: Construction Automation Laboratory–Faculty of Civil and Environmental Engineering, Technion City Shpatnitsky, Y.: Construction Manager, Zemach-Hamerman; formerly, MSc Candidate, Hapoel Hamizrachi St., Kfar Hasidim, Israel Credible publisher, credibility checked authors	3: Top-tier
Objectivity	3	Credible authors, claims are substantiated. Considered objective.	
Accuracy	2	Theory is explained well, also consistent with previous knowledge of industry. Considered accurate.	
Suitability	3	Considered suitable.	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
Integrating automated data acquisition technologies for progress reporting of construction projects (53)	El-Omari, S. Moselhi, O.	2011	Automation in Construction; Elsevier Science B.V., Netherlands	Journal article	Backwards citation chaining	"This paper presents a control model that integrates different automated data acquisition technology to collect data from construction sites required for progress measurement purposes."

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	El-Omari, S.: a Department of Engineering Technology, Missouri Western State University Moselhi, O.: b Department of Building, Civil and Environmental Engineering, Concordia University Credibility checked author	3: Top-tier
Objectivity	3	In accordance with existing research. Considered objective	
Accuracy	2	New model for aquisition of construction data, well explained. Not tested properly. Considedered acceptable	
Suitability	3	Some insight into the different terminology and some methods of data collection. Considered suitable.	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
Real-time resource location data collection and visualization technology for construction safety and activity monitoring applications(82)	Cheng, T. Teizer, J.	2013	Automation in Construction; Elsevier	Journal article	Backwards citation chaining	"State-of-the-art technology in the field of real-time data collection and visualization is reviewed. A novel framework is presented that explains the method of streaming data from real-time positioning sensors to a real-time data visualization platform"

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Cheng, T.: Exxon Mobil Corporation, Irving, United States Teizer, J.: Ruhr-Universitat Bochum, Bochum, Germany Written at: School of Civil and Environmental Engineering, Georgia Institute of Technology Credibility checked author	3: Top-tier
Objectivity	3	Credible author, claims are substantiated. Considered objective.	
Accuracy	3	Three case studies, well explained. Considered accurate.	
Suitability	2	Some relevance. Considered suitable.	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
Assessing research issues in Au tomated Project Performance Control (APPC)(107)	Navon, R. Sacks, R.	2007	Automation in Construction; Elsevier B.V., Netherlands	Journal article	Backwards citation chaining	"The paper presents a new tool with which the gap between the desired functionality of control information systems and that provided in current construction practice can be identified."

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Navon, R.: Construction Automation Laboratory–Faculty of Civil and Environmental Engineering, Technion City Sacks, R.: Faculty of Civil and Environmental Engineering, Technion–Israel Institute of Technology, Haif Credibility checked author	3: Top-tier
Objectivity	3	Reoccuring author. No bias detected. Considered objective.	
Accuracy	3	Considered accurate.	
Suitability	3	An overview of some of the larger obstacles of automated data collection. Considered suitable.	

Pertinent data

Title + (# citations in Scopus)	Author(s)	Year	Source; Publisher	Type document	Acquisition	Scope/goal
Reduction of short-interval GPS data for construction operations analysis(38)	Hildreth, J. Vorster, M. Martinez, J.	2005	Journal of Construction Engineering and Management; ASCE	Journal article	Backwards citation chaining	"This work developed a methodology for making equivalent decisions based on GPS data and presents the procedures developed to identify the key records necessary to calculate activity durations."

COAS - Evaluation

Criteria	Score	Justification	Final score
Credibility	3	Hildreth, J.: Senior Research Associate, Virginia Polytechnic Institute and State Univ., Blacksburg, Vorster, M.: Professor of Construction Engineering and Management, Polytechnic Institute and State Univ., Blacksburg Martinez, J.: Associate Professor, Polytechnic Institute and State Univ., Blacksburg, Credibility checked author	3: Top-tier
Objectivity	3	Considered objective.	
Accuracy	3	Considered accurate.	
Suitability	3	Some relevance. Considered suitable.	

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Interview report

Status: Approved

Interviewer: Ole Simon Tveiten

Subject/interviewee: Hans Petter Dæhli

Position: Service manager in the technical department

Company: Nasta AS, import, sale and total service of construction machinery.

Date: 20.02.2018-28.02.2018

Method: E-mail correspondence

Reservations:

This interview report consists of excerpts from an ongoing e-mail correspondence with Hans Petter Dæhli. Due to the correspondence being introductory, relaxed and exploratory in terms of establishing contact with the industry the full content will not be disclosed. The content that is provided here however was considered relevant to the objectives of the thesis. Furthermore, the correspondence was in Norwegian, and was translated in order to be used in the thesis. Early in the correspondence the interviewee presented a typical monthly report which the users of ConSite have access too, which is relevant to some of the questions.

Interview:

- Interviewer: Besides the standard content of the report, does the user have access to any additional data (loading cycle times for instance)? And are there any supplementary services available which can provide the user with additional data (extra hardware)?

Interviewee: No. There are no available supplementary services for such use. Neither cycle times or weight/mass are measurable at the moment. The challenge is that the machines are performing all kinds of different operations in short periods of time. Typically cycle times are more relevant when the weight of the machine exceeds 50-tons, mainly due to type of work these machines normally do. This is also problematic when comparing machines. As long as the work presents differences, there is little data that can be used to measure efficiency. Fuel consumption however is fairly well managed by our system, as the number of similar machines is quite high. The basis for a good average is certainly present. In the case wheel loaders and dumper trucks, the indicators you are talking about are more relevant.

- I assume the monthly reports ConSite provides are available the provider of the system along with owner of the machine. Are there options in terms of having these reports sent to other stakeholders as well? For example: site manager, project manager and project client.

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Yes. I can forward the report to anyone who wishes it, as long as I have an e-mail to send it to. In practice this is not normally done unless the owner of the machine has asked me to.

- Does the machine operator have access to daily data onboard his machine? And what data if this the case?

Most data is available from the onboard monitor. In practice however, fuel consumption is probably the only data used by the operator. One reason for this might be that the system onboard the machine is not made for producing user friendly reports. Furthermore, the operators are mostly concerned with doing the work that they are assigned and are not payed to analyse data. On the other hand, idling is something some operators probably should take a look at

- How would you describe the differences between ConSite and other similar systems?

I do not have insight of the inner workings of our competitor's systems. Feedback from our users are positive, also when comparing to other systems of similar functions.

- One of the presumptions of my thesis is that by using geospatial data, geological surveys and systems such as ConSite, might be able to provide data such as daily volume which could be useful for project managers. Any thoughts on that?

There are increasing numbers of machines which are delivered with GPS guidance for excavation. Systems such as Leica, provides 3D systems which makes it possible for operators to see where and what to dig. This is based on geospatial data. Using this in combination with specification of the machine, should present opportunities to extract useful figures.

- The top diagram on page 3 of the report illustrates quantity of hours in terms of the different operations a machine has performed. The entries such as Front Operation Hours and Swing Operation Hours seem to give basis for a cycle time calculation. Are these produced as a result of measuring hydraulic pressure? How often is the data registered?

A simplistic version on how the hydraulics works on an excavator: Excavators has two separate hydraulic systems. One main circuit and a pilot circuit. The main pumps (main circuit) produces high pressure which provides power to arms, swing motor, tracks and other accessories. The pilot system has a much lower pressure (max 40 bar) and it is this circuit that control the main circuit. The levers in the cab are fed pilot pressure. When using the levers, a response fed is sent the spool valve which determines the pressure which is to be forwarded from the main circuit.

The diagrams you are referring is produced by registering the time in which the pilot system is active. When the pilot system is "ordered" by the operator to raise pressure in for example the swing motor, the time frame of which this pressure is active is registered. The time is logged continuously, but I do not believe the corresponding pressure is registered.

- You mentioned that it is typically more beneficial to use calculations of cycle times when dealing with larger machines and more permanent construction sites, are there any services provided by ConSite for these kinds of operations?

No. On large scale construction operations we use theoretical values provided by Hitachi. This is also used for providing the customer with the optimal size of machine.

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Interview report:

Status: Approved

Interviewer: Ole Simon Tveiten

Subject/interviewee: Marius Engstrøm

Position: Key account manager

Company: Volvo AS, distribution, sale and total service of construction machinery.

Date: 21.03.2018 **Time:** 13.00.

Method: Interview.

Reservations:

This interview report consists of excerpts from a meeting at Volvo AS Oslo with Marius Engstrøm. The content that is provided here however is considered relevant to the objectives of the thesis. Furthermore, the meeting was in Norwegian, and was translated in order to be used in the thesis.

Interview:

- Interviewer: In context to my thesis, what systems are available to your costumers today?

Interviewee: Well, Volvo offers the CareTrack system which daily produces data such as map and coordinates, total hours, idle hours, waiting hours, mileage, fuel consumption, engine RPM and cycle times.

- How do these systems operate and what functions are available?

CareTrack registers these parameters every 24 hours and produces weekly and monthly reports which is forwarded to the client if they have subscribed to this service. Some of this data is available online through the CareTrack site if the client is interested. Data such as location of machine, fuel level and consumption and more is available there.

- Through earlier interviews I have noticed that cycle times rarely are taken into consideration? Is this data available to the client?

Cycle times are not represented in the weekly or monthly PDF Fuel-reports. In the online service cycle times are available only for articulated dump trucks as a part of the productivity package. Productivity data can be found as production data if onboard weighing system is installed on the articulated dump truck and customer subscribes for this data. The data material is presented on a daily basis as average %-figures. In the current Caretrack system single-cycle data is not available either to Volvo dealer or customer. There is a demand from customers for single cycle production data, but unfortunately, we cannot supply or obtain it. Volvo is currently introducing to the global market a self-developed brand new productivity system for wheeled loaders and articulated dump trucks called Load assist and Dump assist. The systems are a Tablet-based productivity system, separate from Caretrack. Daily productivity data t.ex. single cycle times are available from this separate system as daily e-mail reports (or printable). It is expected that the systems will be developed further in the coming years and more services will be available.

- What data does the client seem most interested in?

Customers want environmental reports, fuel consumption and c_o^2 production. But this is mainly from performance monitoring systems such as CareTrack, there are other systems such as Trackunit, DigAssist which to some extent ensures quality and progress control.

- How are these systems helpful for Volvo?

Demand for operating- and production data is increasing rapidly in Norway and it is very important for the customers to follow up production and monitoring their fleets. To be able to supply high quality services around this will make Volvo a preferred supplier of construction machinery. As a dealer we use Caretrack mainly for service planning and fleet overview. In some cases operating data can be used when handling warranty- and insurance cases. Also most of the data can be used to further improve and analyse the durability of the equipment.

- Is load measurement ever requested from the client?

Articulated dump trucks do utilize this tech yes, excavators however is less suited due to rough conditions on the equipment used to measure the mass and due to its variable work habits. Measurement of mass is also common on wheel loaders, where loading of a specific mass for sale is often done. Also, excavators used for bay-loading utilize mass measurement. Loadtronic 3 which is provided by Aanderaa is often used on wheel loaders which are specifically used for mass measurement. Loadrite from Trimble also provides several different weighing systems. If measurement- and weighing system installed on a machine and used for trade/sale of masses, the system must be approved by the supplier on behalf of the Norwegian authorities.

- What portion of clients use the CareTrack functions?

It’s hard to say, there are probably accurate numbers on this, but on an educated guess I would say about half.

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Interview report:

Status: Approved

Interviewer: Ole Simon Tveiten

Subject/interviewee: Ingebrigt Storrøseter

Position: Project management

Company: Oppdal Maskinkompani AS, construction contractor.

Date: 22.03.2018 **Time:** 10.00.

Method: Interview.

Reservations:

This interview report consists of excerpts from a meeting and site visit at Oppdal Maskinkompani AS with Ingebrigt Storrøseter. This interview needs to be evaluated in context of the DigPilot system. Also, the interview was kickstarted with an exploratory conversation on the topic of performance monitoring systems and machine control systems. The content that is provided here however is considered relevant to the objectives of the thesis. Furthermore, the meeting was in Norwegian, and was translated in order to be used in the thesis.

Interview:

- Interviewer: What kind of data is available to you through machine control systems?

Interviewee: There are a lot of data that can be produced with right use of such systems. Machine control systems such as Trimble, DigPilot and Leica provide geospatial data in context to the designed project. DigPilot, which we have experience with, provides coordinate and level confirmation through the machine, which means manual measurements during the process in most cases are not needed.

- What is the benefits of such systems?

First of all there are lots of benefits connected to avoiding rework costs. The machine control systems to some extent ensures that the work is done right. There are other benefits as well, too name a few: resource saving in terms of management, increased precision, reduces the margin of error, but also the requirements as a consequence. Also, the margins have a huge impact on earth work.

- What kind of analysis do you do on the data?

We do use these systems to produce key indicators for future reference. Some of them are progress control parameters, cost estimates, resource usage. ProADM, workhour analysis with associated activity.

- Do you find the process of analysing this data cumbersome?

The threshold for performing extensive analysis seems to be to high. As discussed a combination between performance monitoring and machine control systems and workhour analysis would be ideal if it could produce automated parameters.

- Do you think the operators feel uncomfortable being “monitored”?

No, I think it actually aggregates their performance. Furthermore, it’s a force of habit and they get used to it. Its also worth mentioning that it boosts their confidence knowing exactly what is to be done. The need to ask their boss is relieved in most cases.

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Interview report:

Status: Approved

Interviewer: Ole Simon Tveiten

Subject/interviewee: Jan Floberg and Erik Sørngård

Position: CEO

Company: Gundersen og Løken AS, distribution, sale and total service of measuring instruments for the construction industry.

Date: 21.03.2018 **Time:** 10.00.

Method: Interview

Reservations:

This interview report consists of excerpts from a meeting at Gundersen og Løken AS with Jan Floberg and Erik Sørngård. The content that is provided here however is considered relevant to the objectives of the thesis. There was also a brief introduction to what the objectives of my thesis is in order to set the tone for the meeting. The meeting was done in a highly exploratory way, and most of the questions did stray off from the original interview guide. Furthermore, the meeting was in Norwegian, and was translated in order to be used in the thesis.

Interview:

- Interviewer: In context to my thesis, what systems are available to your costumers today?

Interviewee: In general, we import and sell measuring instrument for the construction industry. We also do maintenance and repair for clients in our workshop. We have also produced several patented products, DigPilot being the most significant of these. DigPilot is developed and manufactured in Norway. DigPilot is a machine control system, much in comparison to the Trimble and Leica systems. Although we are a smaller company, we offer services and functions that are unique.

- How do these systems operate and what functions are available?

Well, we developed DigPilot, DigPilot Office and produce hardware which mainly are meant to be used on excavators. The system can be used on dozers, scrapers, dredging machines and more. As for how the system operate, it in principle combines the best features of wireless sensors, terrain models, GPS/GNSS and the DigPilot office to provide a relatively detailed model for the operator, as well as cm-precision. While operating the machine, the operator simply manually logs when the bucket is at the right level and coordinate, which then is sent to the server where they are processed. The same goes for the synchronization process, several locations on the site are sync points, which means the operator can simply drive over and sync the machine with the system without any fuzz. Furthermore, the RTK motor in the rover gives cm-precision for all joints all the way to the bucket.

- What are the benefits of such a system?

When it comes to efficiency, the work is generally done faster since there are no mistakes. Also, every designed element, is shown down to mm precision on the on-board screen in the machine. The machine is also shown in real time. The registered points are accurate and provides ensuring data for the manager. Also, the need for actual manual levelling and coordinate measurements are almost eliminated due to the system providing these while the machine is working. We have reason to believe that our system can produce a 30-50% increase in efficiency. The numbers this produce when looking at fuel consumption alone is staggering, at least on national level.

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Interview report:

Status: Approved

Interviewer: Ole Simon Tveiten

Subject/interviewee: Tim Fredrik Johansen-Hagen

Position: Sales manager

Company: Aanderaa Data Instruments AS, distribution, sale and total service of sensor and system solutions.

Date: 19.04.2018

Method: E-mail correspondance

Reservations:

This interview report consists of excerpts from e-mail correspondence with Tim Fredrik Johansen-Hagen at Aanderaa. The interview must be seen in context of the Loadtronic system that Aanderaa provides, which is a weight system for construction machinery. The content that is provided here however is considered relevant to the objectives of the thesis. Furthermore, the correspondence was in Norwegian, and was translated in order to be used in the thesis.

Interview:

- Interviewer: Which activities does customers use Loadtronic for?

Interviewee: Our clients consists mainly of contractors or larger companies which employ our systems, specifically the Loadtronic 3 and Loadtronic 3E, when measuring weight of rock of varying size.

- What are the benefits of such systems?

The benefits with measuring weight in the bucket are as follows:

I. An overview of inventory/internal use and control.
II. Assurance when selling or purchasing mass(There is a requirement that wheel loaders with weight systems are approved for purchase and sale, and that the initial verification is performed by Justervesenet)
III. Safe loading of trucks in order to prevent overloading and potential fines upon inspection.

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- Do u have any perception of why your clients purchased your system?

Our clients seek an overview of production in order to determine values of production in tons. Some wants to eliminate uncertainty and create assurance with their customers when purchasing or selling mass.

- Is the system compatible with other performance monitoring systems such as VisionLink, ConSite, Caretrack, etc.?

Loadtronic 3 is not compatible with other programs/systems but communicates a string of information through a RS232 port. It is possible to process this data and convert it to Excel or other third party software(f.ex Visma, Online scale, Smartdoc etc.)

- Some systems transfer data packets at certain intervals in time, how does Loadtronic handle this in regards to wireless transfer of the registered data at site?

Through the RS232 port it is possible to transfer the data by means of a modem. There are some limitations to what data that can be gathered this way, but you get a string of information when the operation is done.

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Interview report:

Status: Approved

Interviewer: Ole Simon Tveiten

Subject/interviewee: Nils Magne Egset

Position: CEO

Company: OK Entreprnør AS, construction contractor.

Date: 06.04.2018 **Time:** 12.30.

Method: Interview.

Reservations:

This interview report consists of excerpts from a meeting at OK Entreprenør AS with Nils Magne Egset. The content that is provided here however is considered relevant to the objectives of the thesis. Furthermore, the meeting was in Norwegian, and was translated in order to be used in the thesis.

Interview:

- Interviewer: What kind systems do you use?

Interviewee: We use SCS 900 Trimble machine control system. However we do not use Business Center for our design process. We use Topocad for design, then we export the file to be compatible with BC in order to properly use the designdata in our machines. We use SmartDok to manage work hours. I know that Risa uses a different system with high success, although I cant remember what that system is called right now. Furthermore we also use connected community provided by Trimble as a performance monitoring system. We do not really use VisionLink, only to manage fuel consumption and idle times.

- What is the benefits of such systems?

The Trimble system is great. The system allows for manual logging of leveling and coordinate data by machine operator. This can be done automatically but the amount of data that produces is to large for any use. Progression is therefore done by manually registering the level and coordinates of each layer of mass. The volume is calculated from this if the specific project calls for it. There are however some downsides, as mentioned we use Topocad, which is not immediately compatible with the Trimble system. Furthermore the machine does not "gather"

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the information from the BC directly(automatically), we need to send the information to each machine manually.

- What kind of analysis do you do on the data?

Well, we do not generally perform any analysis, our project are not “supersized” which leaves any analysis cumbersome compared to its benefits. Also the excavators do a large variety of different work. We do, as mentioned, manage progress and volume in most instances.

- Is there any data you would like to have access to that is currently not present?

In my opinion the problem seems to be compatibility. Also it is worth mentioning that for larger projects, where we are hired as a contractor, if there is a BIM-model, it lacks sufficient info. Specifically the coordinates, which makes it useless in terms of use in systems such as Trimble.

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Interview report:

Status: Approved

Interviewer: Ole Simon Tveiten

Subject/interviewee: Magnus Holmsen

Position: Site manager

Company: AF Gruppen AS, construction contractor and developer

Date: 19.03.2018 **Time:** 12.00.

Method: Interview.

Reservations:

This interview report consists of excerpts from a meeting and site visit at AF Gruppen AS with Magnus Holmsen. The content that is provided here however is considered relevant to the objectives of the thesis. Furthermore, the meeting was in Norwegian, and was translated in order to be used in the thesis.

Interview:

- Interviewer: In context to my thesis, what systems are available to you?

Interviewee: Well, at this site there is an extensive amount of construction machines from different providers. Each brand comes with its, maybe several, own systems of performance monitoring systems. The main ones however are VisionLink and CareTrack.

- What are the benefits of such systems?

Well, we don't really use these systems to their full extent. We mainly use them as a reference when performing our progress control. It is useful as a basis of comparison. We also use it when monitoring fuel consumption.

- What system do you use for performance monitoring?

We use SmartDok, which is generally used for managing work hours. However we use an extended version which provides additional data.

- What kind of data does this system produce?

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The machine operators can manually specify the location of loading, what machine they are using, type of mass, each loading sequence is logged as well. This data is then used in a “homemade” excel sheet. This produces a valuable database which consists of: type of mass, type of machine, operator identity, date, location, where the mass was gathered and delivered and amount in m^3. The volume produced is calculated from these parameters: factory specifications and number of loads. Also this is adjusted from experience.

- What is the reason for not using the performance monitoring systems available?

There are several reasons for this, although the main one being that there is simply too many of them to properly implement a functioning system within a reasonable amount of work. It is simply put less work to establish an own system which provides the parameters I need, than to manage all of them at once. Furthermore there are several of our machine which are older and does not have the same version of the systems as the newer ones, or even don’t have any system at all.

- Do you find the process of analysing this data cumbersome?

No, or well yes if that means using all the systems that are provided by the machines. The process using our system is within a reasonable amount of work. When it comes to volume, which is probably the most important factor I monitor, it is based on truck volume. The excavator production efficiency is extrapolated from this.

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Interview guide:

Background/purpose

The main purpose is to explore the potential of ADC systems on excavators in terms of productivity. This goal presents a large and quite vague scope. The interview must reflect the objectives of the thesis:

- What kind of data is registered by ADC systems?
- Does the registered data provide sufficient information i regards to measuring productivity and production?
- How is the data used today?

Every interview report should provide the following information about the interview:

- **Status***(Approved/not yet approved)*
- **Interviewer:** *Identity of the interviewer*
- **Subject/interviewee:** *Identity of the interviewee*
- **Position:** *Position within the company of the interviewee*
- **Company:** *Company name*
- **(Time) and Date:** *Date of the interview and time if possible(not the case in e-mail correspondence.*
- **Method:** *How was the interview carried out*

Rules:

The timespan, purpose and other relevant information is to be made clear to the interviewee before asking any questions. Furthermore, the interviewee is allowed to digress as long as the topic is within reasonable reach of the objectives. Follow up questions are to be made if deemed in the best interest of gathering relevant information. If the role of the interviewee is hard to define or the situation calls for it, a mix of the questions are allowed. The interviews are to be recorded by means of topic specific keywords that after the interview are to immediately be transcribed for a fully presentable interview report. The interview reports need to be approved by the interviewee before any use.

Field experts and System providers:

- What systems are available to costumers today?
- How do these systems operate and what functions are available?
- What are the intentions with providing customers these systems?
- Are these systems in use, and at what percentage of the population?

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Management:

- What kind of data is available to you through machine control systems, ADC systems and similar systems?
- What is the benefits of such systems?
- What kind of analysis do you do on the data?
- Do you find the process of analysing this data cumbersome?
- Is there any data you would like to have access to that is currently not present?

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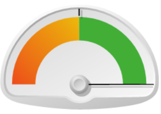
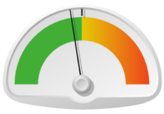
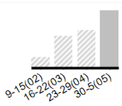
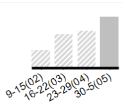
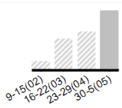
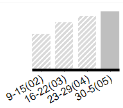
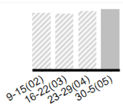
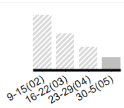
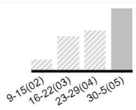
Volvo Construction Equipment

FUEL EFFICIENCY

This report includes all of your Volvo machines, by site and job task.

DEALER	CUSTOMER	REGION	SITE
VOLVO MASKIN AS	**AF Gruppen Norge AS**	**AF Anlegg**	**Tvedestrand-Arendal Forbindelsen**
CONTACT Marius Engström +47 92 69 69 25 marius.engstrom@volvo.com	CONTACT Tom Rainer Nilsen +4790547782 tom.rainer.nilsen@afgruppen.no	CONTACT	CONTACT
ISSUE DATE: 10th of Feb 2017	PERIOD: 30th of Jan - 5th Feb 2017 (week 05)	REPORT SCOPE: Machines operating on site - Tvedestrand-Arendal Forbindelsen	

	Total 21 Machines		Work Machine utilized		Idle Machine partly utilized		CO_2 Emissions
	Fuel Consumption	Hours	Fuel consumption during work	Utilization	Wait (< 5 min)	Excessive Idle (> 5 min)	
30th of Jan - 5th Feb 2017 (week 05) Result:	**13 013 Litres** 130 133 NOK	**828 Hours**	**11 242 Litres** 112 425 NOK	**55%** 454 Hours	**38%** 14 934 NOK	**7%** 2 774 NOK	**33.83 Tonnes CO_2**
Objective:	11 661 Litres 116 605 NOK	577 Hours	11 297 Litres 112 972 NOK	63% 530 Hours	27% 10 546 NOK	10% 3 839 NOK	30.32 Tonnes CO_2
Results compared to objectives:	 Above objective: 1 353 Litres 13 528 NOK	 Above objective: 250 Hours	 Below objective: 55 Litres 547 NOK	 Below objective: 8% 76 Hours	 Above objective: 11% 4 388 NOK	 Below objective: 3% 1 064 NOK	 Exceeded: 3.52 Tonnes CO_2
Trend of actual figures:							

1. Summary by Application

The table shows efficiency data for individual machines, grouped by application.

	Total			Work Machine utilized			Idle Machine partly utilized	
	Hours	Ltrs	L/h	Utilization	Ltrs	L/h During work	Wait (< 5min) Hours	Excessive idle (> 5min) Hours
Total (21)	**828**	**13 013**	**15.7**	**55%**	**11 243**	**24.8**	**316**	**58**
Other Building (18)	**696**	**10 170**	**14.6**	**51%**	**8 546**	**23.9**	**291**	**48**
A40 (7)	**328**	**4 605**	**14.0**	**47%**	**3 652**	**23.4**	**150**	**22**
AFS 12-7337 (A40G340190)	67	987	14.8	61%	874	21.4	22	4
AFS 12-7336 (A40G340186)	37	341	9.3	30%	243	22.2	22	3
AFS 12-7339 (A40G340247)	37	366	9.9	30%	259	23.3	25	1
AFS12-7333 (A40F012288)	49	640	12.9	37%	432	23.8	29	2
AFS12-7331 (A40F012101)	69	1 133	16.5	57%	951	24.2	25	4
AFS12-7334 (A40F012291)	70	1 130	16.2	50%	885	25.2	26	9
AFS12-9901 (A40F012352)		8	22.4	63%	7	29.9		0
EC220 (1)		**1**	**5.4**	**37%**	**1**	**9.6**		**0**
AFS21-0050 (C220E321043)		1	5.4	37%	1	9.6		0
EC480 (3)	**133**	**3 879**	**29.2**	**70%**	**3 586**	**38.8**	**33**	**8**
AFS21-0056 (C480E310531)	24	507	21.4	51%	426	35.5	9	3
AFS21-7149 (EC480210305)	55	1 631	29.8	77%	1 527	36.1	11	2
AFS21-7155 (EC480210413)	54	1 740	32.0	70%	1 633	42.7	13	3
EC750 (1)	**7**	**99**	**13.6**	**24%**	**55**	**31.8**	**5**	**1**
AFS21-0061 (C750E310021)	7	99	13.6	24%	55	31.8	5	1
EW160 (2)	**94**	**804**	**8.6**	**64%**	**740**	**12.3**	**20**	**13**
AFS 21-0029 (EW160220549)	40	253	6.3	54%	219	10.1	9	9
AFS 21-0040 (EW160221030)	54	551	10.3	72%	522	13.5	11	4
L180 (2)	**36**	**380**	**10.7**	**38%**	**234**	**17.4**	**17**	**5**
AFS22-0056 (L180G022126)	6	65	11.1	51%	50	16.5	2	1
AFS 22-0063 (L180H003495)	30	315	10.6	35%	184	17.7	15	4
L90 (2)	**98**	**402**	**4.1**	**34%**	**279**	**8.4**	**65**	**0**

	Total			Work Machine utilized			Idle Machine partly utilized	
	Hours	Ltrs	L/h	Utilization	Ltrs	L/h During work	Wait (< 5min) Hours	Excessive idle (> 5min) Hours
Total (21)	**828**	**13 013**	**15.7**	**55%**	**11 243**	**24.8**	**316**	**58**
AFS22-0066 (L90H013308)	49	219	4.5	42%	164	8.0	28	0
AFS22-0059 (L90H013101)	49	184	3.7	26%	115	8.9	37	0
Grain/Crop Handling/Silage making (3)	**132**	**2 843**	**21.6**	**74%**	**2 696**	**27.8**	**25**	**10**
A40 (1)	**3**	**29**	**10.8**	**38%**	**22**	**21.6**	**1**	**1**
Rental (A40G340041)	3	29	10.8	38%	22	21.6	1	1
EC300 (1)	**71**	**1 168**	**16.5**	**74%**	**1 136**	**21.6**	**12**	**6**
AFS 21-7145 (EC300210543)	71	1 168	16.5	74%	1 136	21.6	12	6
EC380 (1)	**58**	**1 645**	**28.4**	**75%**	**1 538**	**35.5**	**12**	**3**
AFS21-7147 (EC380210451)	58	1 645	28.4	75%	1 538	35.5	12	3

2. Focus List

The table only shows machines where the results during the period does not reach objective levels.
Machines in yellow status are between objective level and red level.

Machines not reaching their objectives, in the current week, led to a deviation compared to the objectives amounting to:

Total fuel l/h (including idle)	2 439 Litres	
Working fuel l/h (excluding idle)	957 Litres	
Minimum distance	740 Km	
Excessive idle (% of total machine hours)	9 Hours	(36 Litres)
Total machine hours	71 Hours	
Machine utilization (% of total machine hours)	98 Hours	
H-mode usage for EXC (% of working hours)	596 Litres	
P-mode usage for EXC (% of working hours)	335 Litres	

Machine	Total Consumption	Total Hours	Objectives not fulfilled: Objective		Result				
Grain/Crop Handling/Silage making									
AFS21-7147 (EC380210451), Grain/Crop Handling/Silage making	1 645 Litres	58	H-mode usage for EXC (% of working hours) Interim objective: System generated	5.0 %	75.0 % Loss 146.4 Litres	9-15(02)	16-22(03)	23-29(04)	30-5(05)
			P-mode usage for EXC (% of working hours) Interim objective: System generated	1.0 %	1.8 % Loss 7 Litres	9-15(02)	16-22(03)	23-29(04)	30-5(05)
			Total fuel l/h (including idle) Interim objective: System generated	11.4 l/h	28.4 l/h Loss 987.8 Litres	9-15(02)	16-22(03)	23-29(04)	30-5(05)
			Working fuel l/h (excluding idle) Interim objective: System generated	28.2 l/h	35.5 l/h Loss 315 Litres	9-15(02)	16-22(03)	23-29(04)	30-5(05)
AFS 21-7145 (EC300210543), Grain/Crop Handling/Silage making	1 168 Litres	71	H-mode usage for EXC (% of working hours) Interim objective: System generated	5.0 %	55.9 % Loss 172.1 Litres	9-15(02)	16-22(03)	23-29(04)	30-5(05)
			Total fuel l/h (including idle) Interim objective: System generated	9.3 l/h	16.5 l/h Loss 509.8 Litres	9-15(02)	16-22(03)	23-29(04)	30-5(05)
			Working fuel l/h (excluding idle) Interim objective: System generated	15.7 l/h	21.6 l/h Loss 310.5 Litres	9-15(02)	16-22(03)	23-29(04)	30-5(05)
Rental (A40G340041), Grain/Crop Handling/Silage making	29 Litres	3	Excessive idle (% of total machine hours) Interim objective: System generated	10.0 %	23.6 % Loss .4 Hours (1.4 Litres)	9-15(02)	16-22(03)		30-5(05)
			Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	38.2 % Loss .6 Hours	9-15(02)	16-22(03)		30-5(05)
			Minimum distance Interim objective: System generated	71.8 Km	10.6 km Loss 61.2 Km	9-15(02)	16-22(03)		30-5(05)
			Total fuel l/h (including idle) Interim objective: System generated	10.5 l/h	10.8 l/h Loss 1 Litres	9-15(02)	16-22(03)		30-5(05)

	Total		Objectives not fulfilled						
	Consumption	Hours	Objective		Result				
Rental (A40G340041), Grain/Crop Handling/Silage making	29 Litres	3	Total machine hours Interim objective: System generated	17.7 Hours	2.7 Hours Loss 14.9 Hours	9-15(02)	16-22(03)		30-5(05)
Other Building									
AFS12-7331 (A40F012101), Other Building	1 133 Litres	69	Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	57.2 % Loss 1.9 Hours	9-15(02)	16-22(03)	23-29(04)	30-5(05)
AFS12-7333 (A40F012288), Other Building	640 Litres	49	Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	36.8 % Loss 11.5 Hours	9-15(02)	16-22(03)	23-29(04)	30-5(05)
			Minimum distance Interim objective: System generated	171.5 Km	124.1 km Loss 47.4 Km	9-15(02)	16-22(03)	23-29(04)	30-5(05)
AFS12-7334 (A40F012291), Other Building	1 130 Litres	70	Excessive idle (% of total machine hours) Interim objective: System generated	10.0 %	12.4 % Loss 1.7 Hours (11.9 Litres)	9-15(02)	16-22(03)	23-29(04)	30-5(05)
			Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	50.4 % Loss 6.7 Hours	9-15(02)	16-22(03)	23-29(04)	30-5(05)
			Total fuel l/h (including idle) Interim objective: System generated	14.1 l/h	16.2 l/h Loss 147.6 Litres	9-15(02)	16-22(03)	23-29(04)	30-5(05)
AFS12-9901 (A40F012352), Other Building	8 Litres	0	Minimum distance Interim objective: System generated	31.0 Km	2.4 km Loss 28.6 Km	9-15(02)	16-22(03)		30-5(05)
			Total fuel l/h (including idle) Interim objective: System generated	9.7 l/h	22.4 l/h Loss 4.6 Litres	9-15(02)	16-22(03)		30-5(05)
			Total machine hours Interim objective: System generated	16.0 Hours	0.4 Hours Loss 15.7 Hours	9-15(02)	16-22(03)		30-5(05)
			Working fuel l/h (excluding idle) Interim objective: System generated	27.9 l/h	29.9 l/h Loss .5 Litres	9-15(02)	16-22(03)		30-5(05)
AFS22-0059 (L90H013101), Other Building	184 Litres	49	Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	26.2 % Loss 16.7 Hours	9-15(02)	16-22(03)	23-29(04)	30-5(05)
			Total fuel l/h (including idle) Interim objective: System generated	3.3 l/h	3.7 l/h Loss 20.9 Litres	9-15(02)	16-22(03)	23-29(04)	30-5(05)
			Working fuel l/h (excluding idle) Interim objective: System generated	4.7 l/h	8.9 l/h Loss 54.6 Litres	9-15(02)	16-22(03)	23-29(04)	30-5(05)
AFS22-0066 (L90H013308), Other Building	219 Litres	49	Machine utilization (% of total machine hours) Interim objective: System generated	72.7 %	41.9 % Loss 15 Hours	9-15(02)	16-22(03)	23-29(04)	30-5(05)
			Minimum distance Interim objective: System generated	263.4 Km	125.9 km Loss 137.5 Km	9-15(02)	16-22(03)	23-29(04)	30-5(05)
AFS21-7149 (EC480210305), Other Building	1 631 Litres	55	H-mode usage for EXC (% of working hours) Interim objective: System generated	5.0 %	64.8 % Loss 263.6 Litres	9-15(02)	16-22(03)	23-29(04)	30-5(05)
			Machine utilization (% of total machine hours) Interim objective: System generated	78.8 %	77.2 % Loss .9 Hours	9-15(02)	16-22(03)	23-29(04)	30-5(05)
			P-mode usage for EXC (% of working hours) Interim objective: System generated	1.0 %	10.2 % Loss 70.7 Litres	9-15(02)	16-22(03)	23-29(04)	30-5(05)

		Total		Objectives not fulfilled						
		Consumption	Hours	Objective		Result				
	AFS21-7155 (EC480210413), Other Building	1 740 Litres	54	P-mode usage for EXC (% of working hours) Interim objective: System generated	1.0 %	47.7 % Loss 252.9 Litres	9-15(02)	16-22(03)	23-29(04)	30-5(05)
				Total fuel l/h (including idle) Interim objective: System generated	30.8 l/h	32.0 l/h Loss 62.8 Litres	9-15(02)	16-22(03)	23-29(04)	30-5(05)
	AFS 21-0029 (EW160220549) , Other Building	253 Litres	40	Excessive idle (% of total machine hours) Interim objective: System generated	10.0 %	22.7 % Loss 5.1 Hours (9.5 Litres)	9-15(02)	16-22(03)	23-29(04)	30-5(05)
				Machine utilization (% of total machine hours) Interim objective: System generated	70.6 %	54.3 % Loss 6.5 Hours	9-15(02)	16-22(03)	23-29(04)	30-5(05)
	AFS 21-0040 (EW160221030) , Other Building	551 Litres	54	Machine utilization (% of total machine hours) Interim objective: System generated	78.0 %	72.0 % Loss 3.2 Hours	9-15(02)	16-22(03)	23-29(04)	30-5(05)
				Total fuel l/h (including idle) Interim objective: System generated	8.2 l/h	10.3 l/h Loss 113.5 Litres	9-15(02)	16-22(03)	23-29(04)	30-5(05)
				Working fuel l/h (excluding idle) Interim objective: System generated	10.3 l/h	13.5 l/h Loss 126 Litres	9-15(02)	16-22(03)	23-29(04)	30-5(05)
	AFS22-0056 (L180G022126), Other Building	65 Litres	6	Excessive idle (% of total machine hours) Interim objective: System generated	10.0 %	13.9 % Loss .2 Hours (1.2 Litres)	9-15(02)	16-22(03)	23-29(04)	30-5(05)
				Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	51.4 % Loss .5 Hours	9-15(02)	16-22(03)	23-29(04)	30-5(05)
				Minimum distance Interim objective: System generated	74.9 Km	14.9 km Loss 60 Km	9-15(02)	16-22(03)	23-29(04)	30-5(05)
				Total machine hours Interim objective: System generated	29.3 Hours	5.9 Hours Loss 23.5 Hours	9-15(02)	16-22(03)	23-29(04)	30-5(05)
	AFS21-0061 (C750E310021), Other Building	99 Litres	7	H-mode usage for EXC (% of working hours) Interim objective: System generated	5.0 %	35.2 % Loss 11.1 Litres		16-22(03)	23-29(04)	30-5(05)
				Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	23.6 % Loss 2.7 Hours		16-22(03)	23-29(04)	30-5(05)
				P-mode usage for EXC (% of working hours) Interim objective: System generated	1.0 %	1.2 % Loss .4 Litres		16-22(03)	23-29(04)	30-5(05)
	AFS21-0056 (C480E310531), Other Building	507 Litres	24	Excessive idle (% of total machine hours) Interim objective: System generated	10.0 %	13.3 % Loss .8 Hours (5.8 Litres)	9-15(02)	16-22(03)	23-29(04)	30-5(05)
				H-mode usage for EXC (% of working hours) Interim objective: System generated	5.0 %	9.4 % Loss 1.6 Litres	9-15(02)	16-22(03)	23-29(04)	30-5(05)
				Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	50.6 % Loss 2.2 Hours	9-15(02)	16-22(03)	23-29(04)	30-5(05)
				P-mode usage for EXC (% of working hours) Interim objective: System generated	1.0 %	4.9 % Loss 4.2 Litres	9-15(02)	16-22(03)	23-29(04)	30-5(05)
				Total fuel l/h (including idle) Interim objective: System generated	10.4 l/h	21.4 l/h Loss 261.5 Litres	9-15(02)	16-22(03)	23-29(04)	30-5(05)
				Working fuel l/h (excluding idle) Interim objective: System generated	22.9 l/h	35.5 l/h Loss 150.4 Litres	9-15(02)	16-22(03)	23-29(04)	30-5(05)

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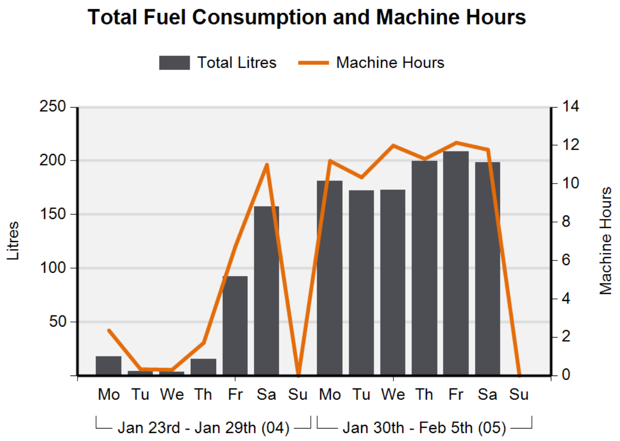
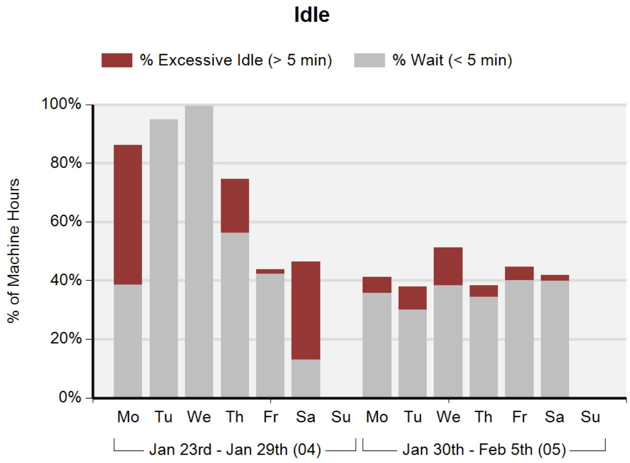
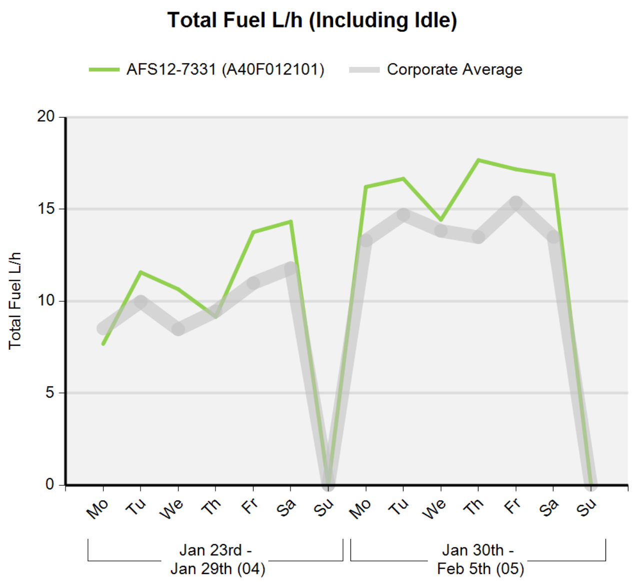
	Total		Objectives not fulfilled						
	Consumption	Hours	Objective		Result				
AFS21-0050 (C220E321043), Other Building	1 Litres	0	H-mode usage for EXC (% of working hours) Interim objective: System generated	5.0 %	98.9 % Loss .9 Litres				30-5(05)
			Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	37.3 % Loss .1 Hours				30-5(05)
			Total fuel l/h (including idle) Interim objective: System generated	5.1 l/h	5.4 l/h Loss .1 Litres				30-5(05)
			Total machine hours Interim objective: System generated	1.4 Hours	0.3 Hours Loss 1.1 Hours				30-5(05)
			Working fuel l/h (excluding idle) Interim objective: System generated	9.1 l/h	9.6 l/h Loss Litres				30-5(05)
AFS 12-7336 (A40G340186), Other Building	341 Litres	37	Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	30.0 % Loss 11 Hours	9-15(02)	16-22(03)	23-29(04)	30-5(05)
			Minimum distance Interim objective: System generated	129.9 Km	83.5 km Loss 46.5 Km	9-15(02)	16-22(03)	23-29(04)	30-5(05)
AFS 12-7337 (A40G340190), Other Building	987 Litres	67	Total fuel l/h (including idle) Interim objective: System generated	9.9 l/h	14.8 l/h Loss 329.1 Litres	9-15(02)	16-22(03)	23-29(04)	30-5(05)
AFS 12-7339 (A40G340247), Other Building	366 Litres	37	Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	30.2 % Loss 11 Hours	9-15(02)	16-22(03)	23-29(04)	30-5(05)
			Minimum distance Interim objective: System generated	316.3 Km	84.3 km Loss 232 Km	9-15(02)	16-22(03)	23-29(04)	30-5(05)
			Total machine hours Interim objective: System generated	39.4 Hours	36.8 Hours Loss 2.5 Hours	9-15(02)	16-22(03)	23-29(04)	30-5(05)
AFS 22-0063 (L180H003495), Other Building	315 Litres	30	Excessive idle (% of total machine hours) Interim objective: System generated	10.0 %	13.6 % Loss 1.1 Hours (6.6 Litres)	9-15(02)	16-22(03)	23-29(04)	30-5(05)
			Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	35.0 % Loss 7.4 Hours	9-15(02)	16-22(03)	23-29(04)	30-5(05)
			Minimum distance Interim objective: System generated	168.6 Km	41.7 km Loss 126.9 Km	9-15(02)	16-22(03)	23-29(04)	30-5(05)
			Total machine hours Interim objective: System generated	43.1 Hours	29.7 Hours Loss 13.4 Hours	9-15(02)	16-22(03)	23-29(04)	30-5(05)

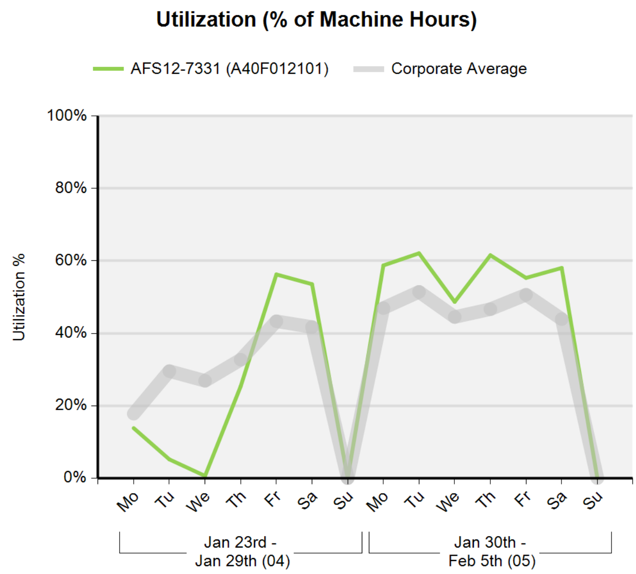
3. Machine: AFS12-7331 (A40F012101) (Model: A40, Application: Other Building)

The following graphs shows you different aspects of fuel consumption.



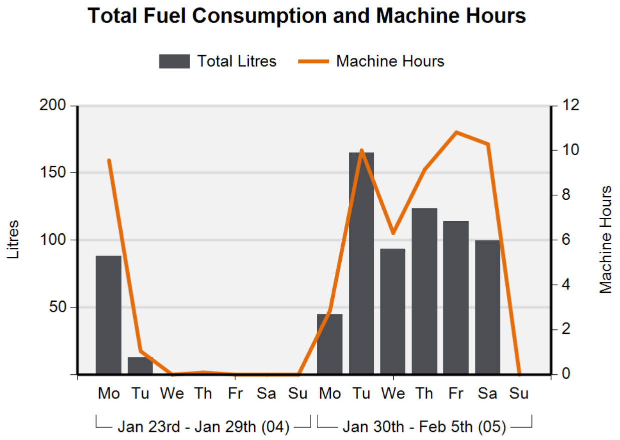


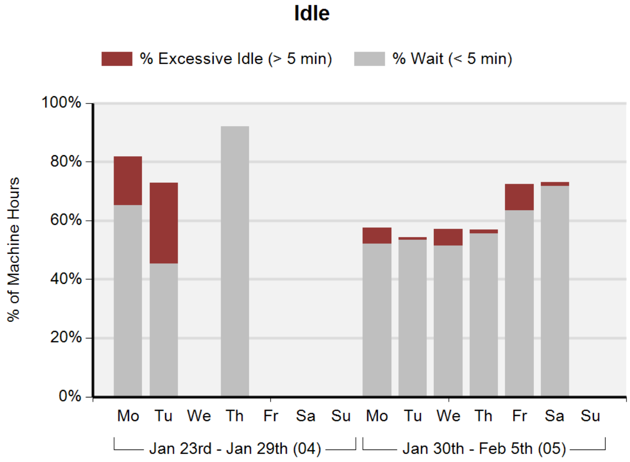


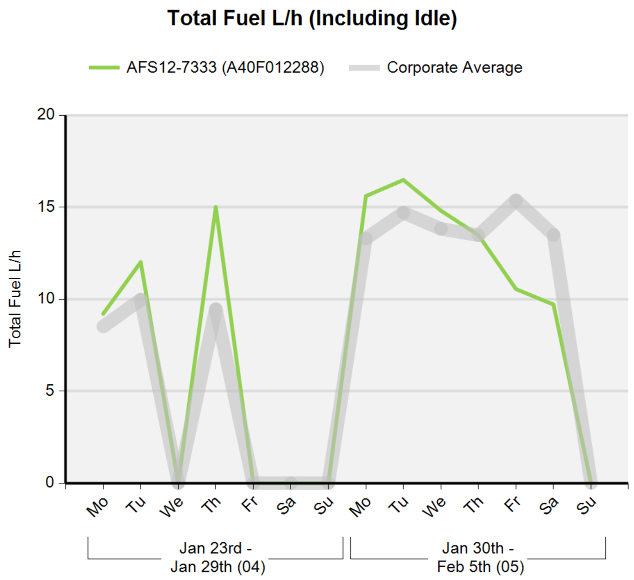


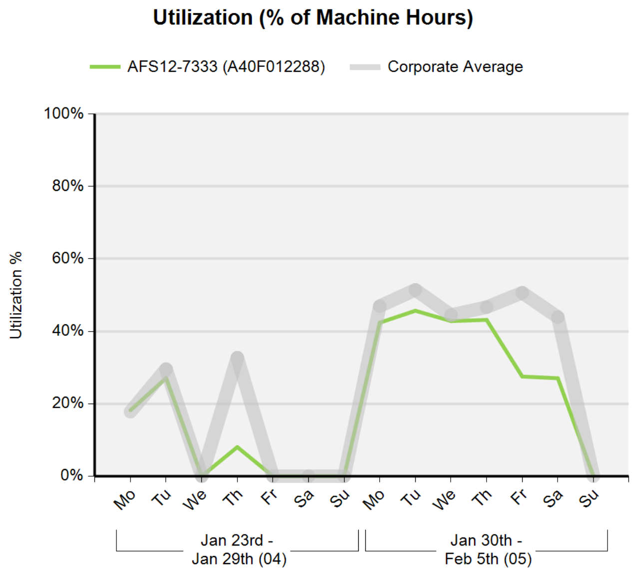
3. Machine: AFS12-7333 (A40F012288) (Model: A40, Application: Other Building)

The following graphs shows you different aspects of fuel consumption.



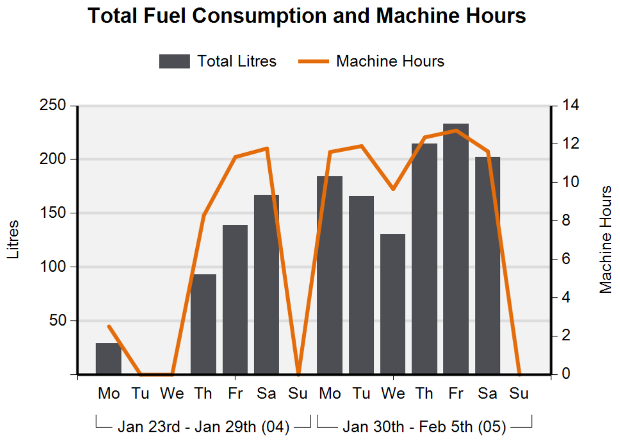


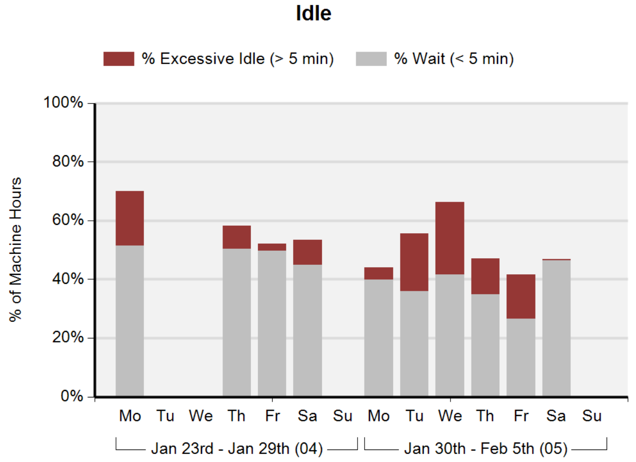


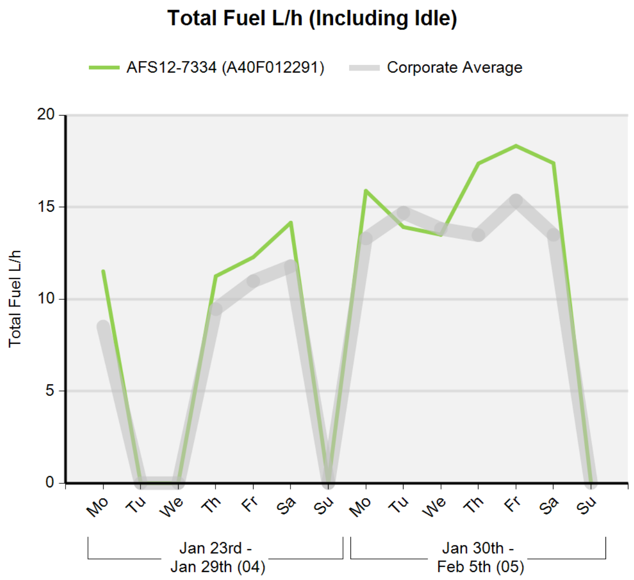


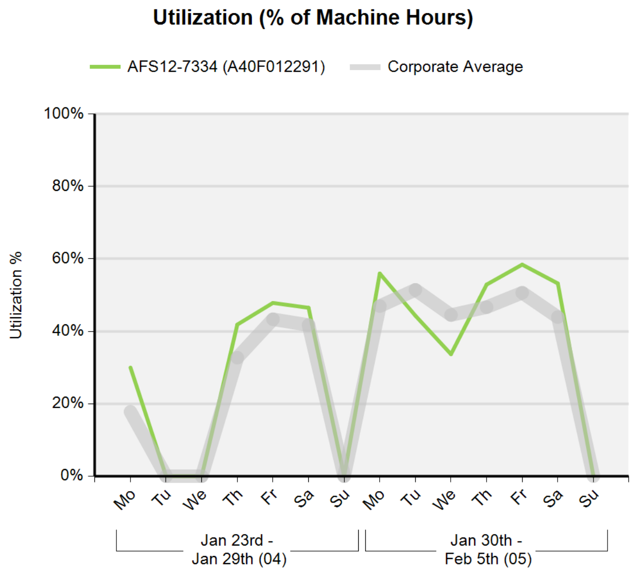
3. Machine: AFS12-7334 (A40F012291) (Model: A40, Application: Other Building)

The following graphs shows you different aspects of fuel consumption.



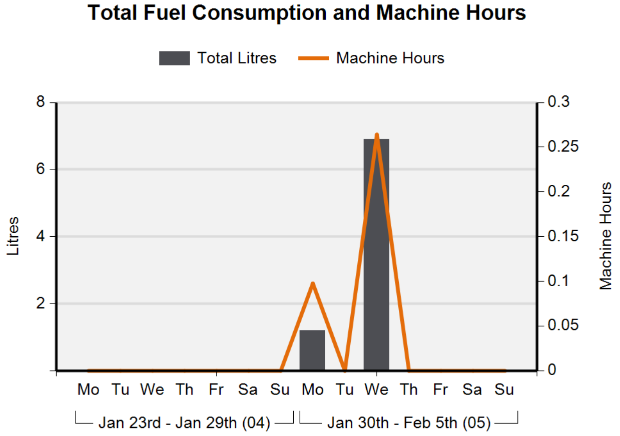


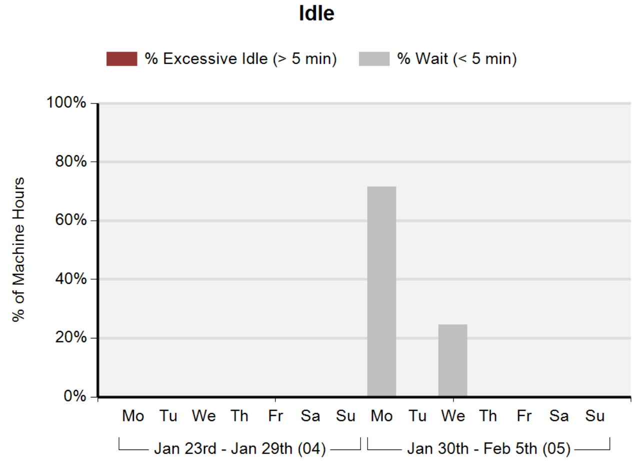


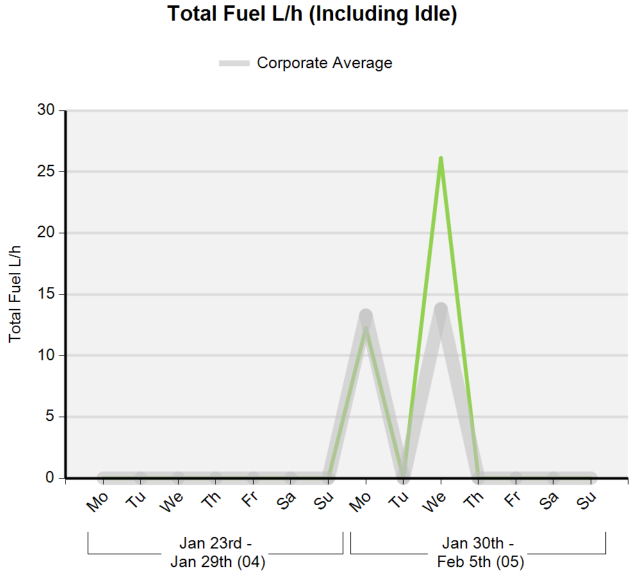


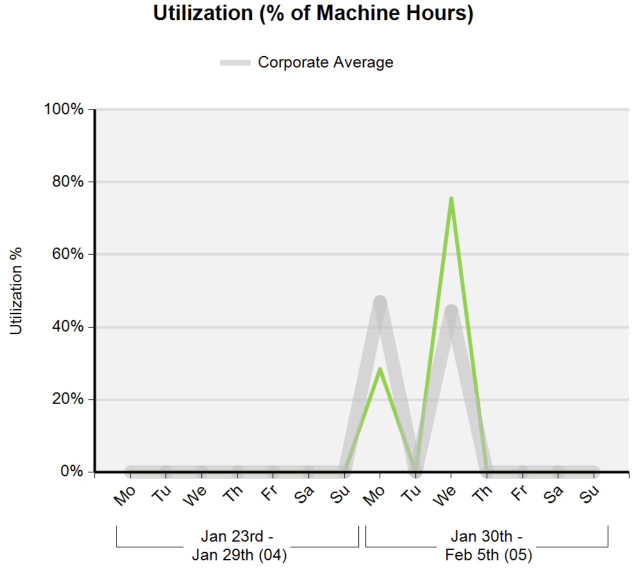
3. Machine: AFS12-9901 (A40F012352) (Model: A40, Application: Other Building)

The following graphs shows you different aspects of fuel consumption.



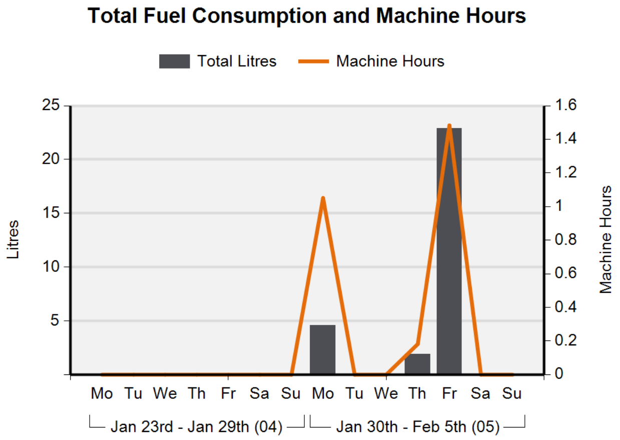


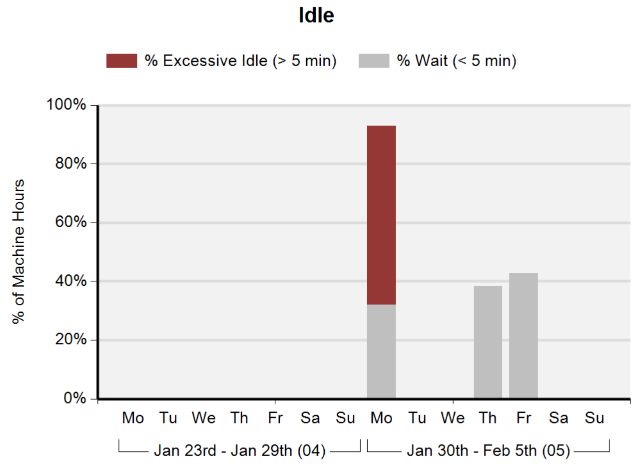


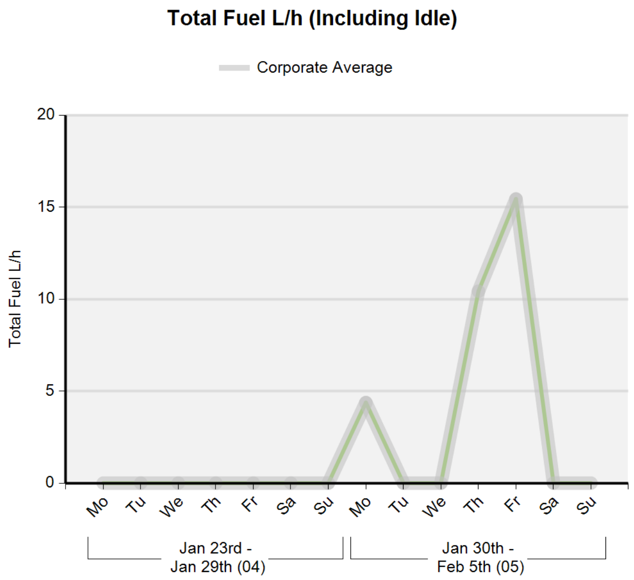


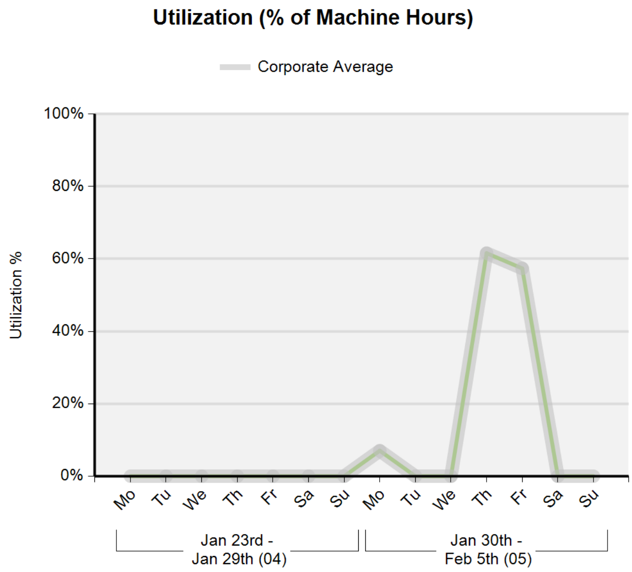
3. Machine: Rental (A40G340041) (Model: A40, Application: Grain/Crop Handling/Silage making)

The following graphs shows you different aspects of fuel consumption.



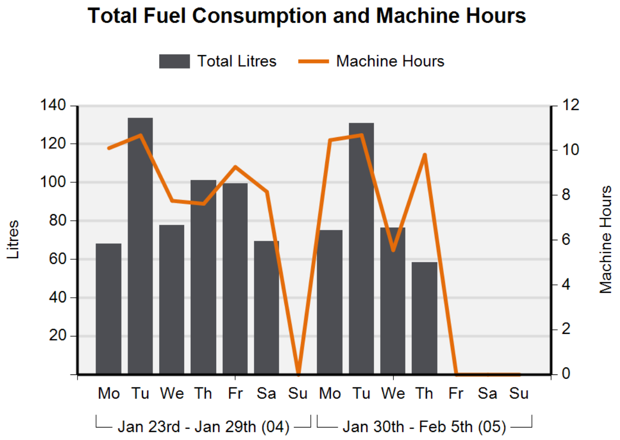


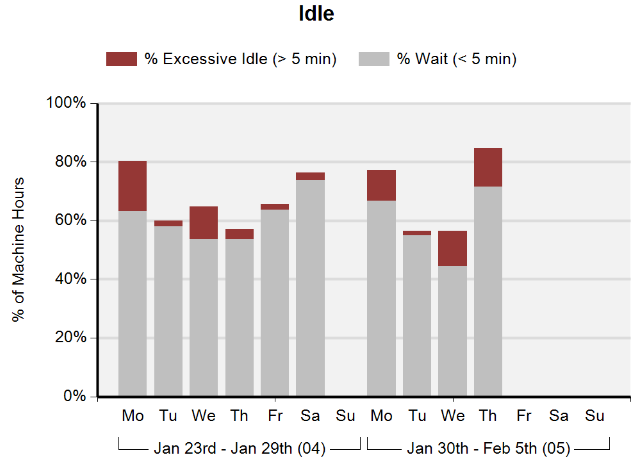


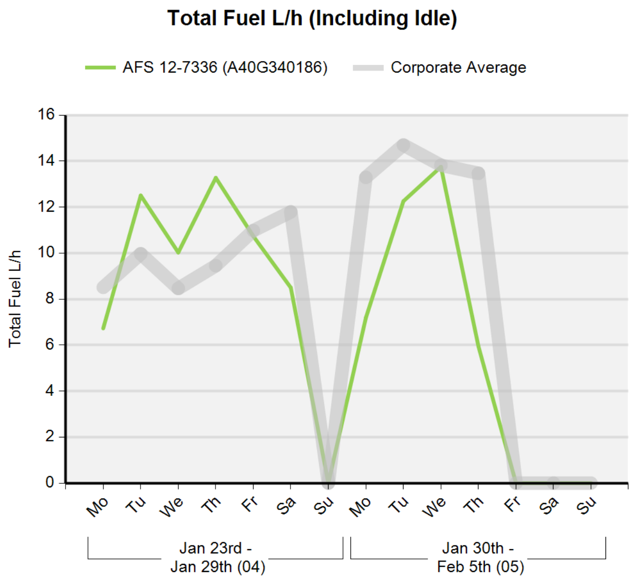


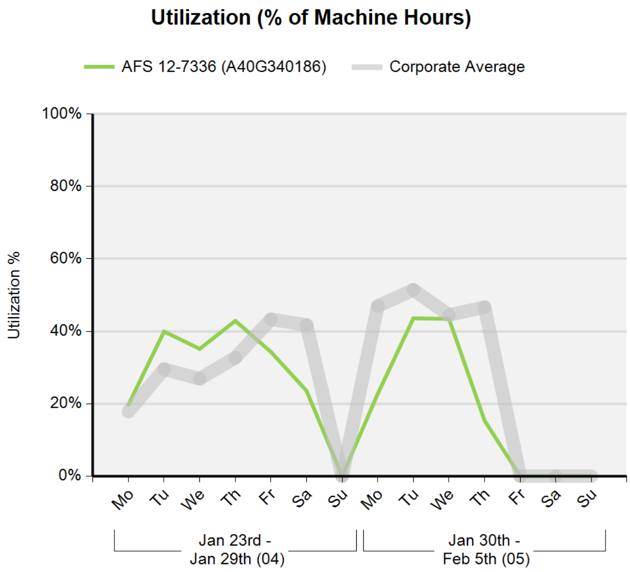
3. Machine: AFS 12-7336 (A40G340186) (Model: A40, Application: Other Building)

The following graphs shows you different aspects of fuel consumption.



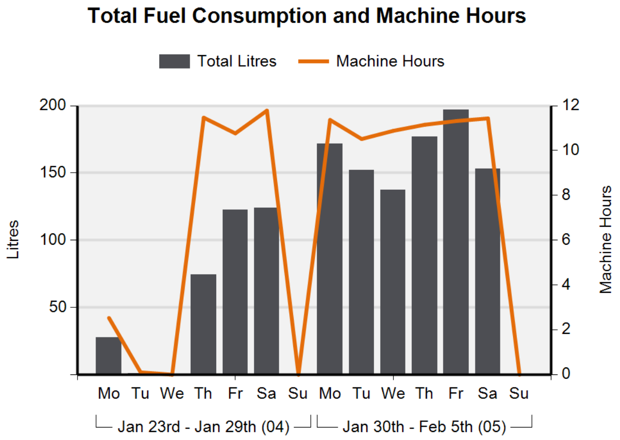


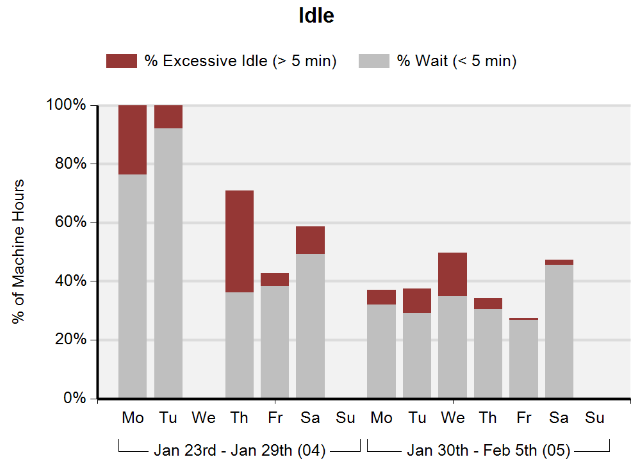


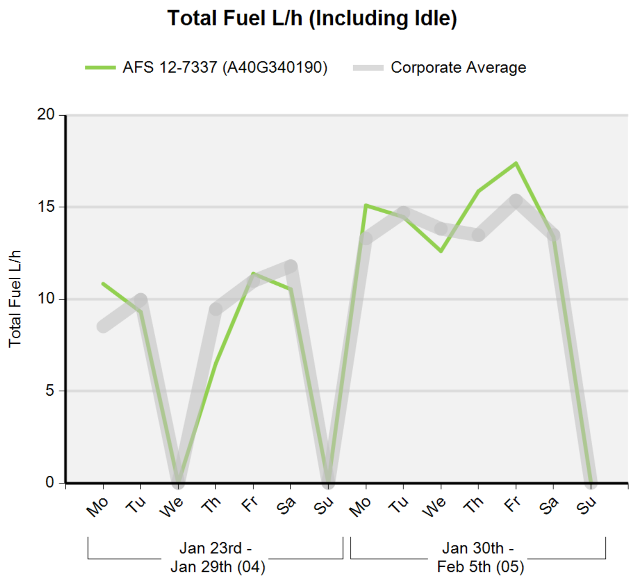


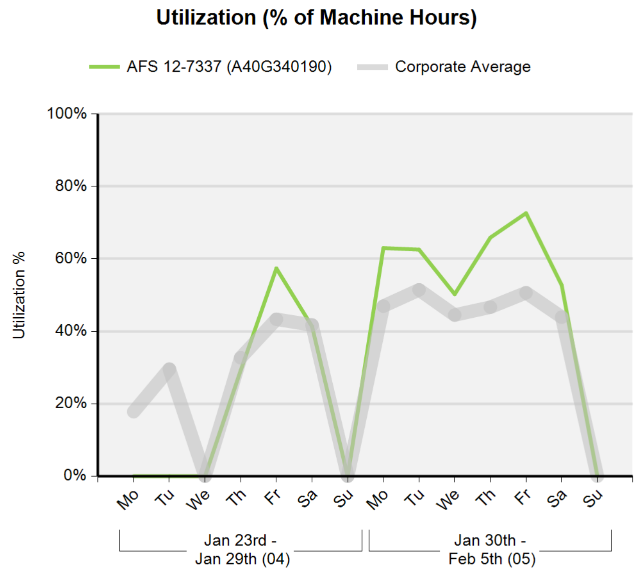
3. Machine: AFS 12-7337 (A40G340190) (Model: A40, Application: Other Building)

The following graphs shows you different aspects of fuel consumption.



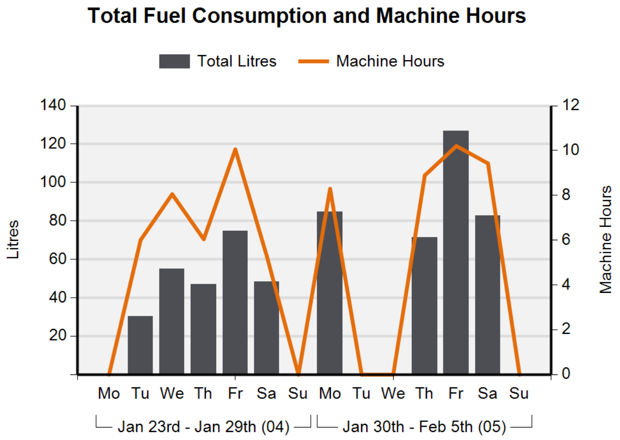


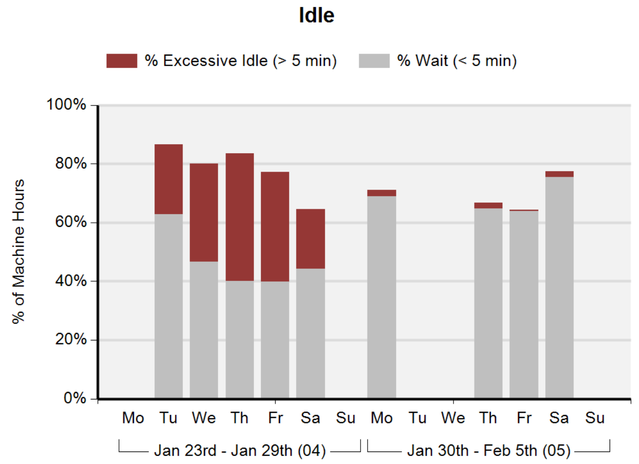


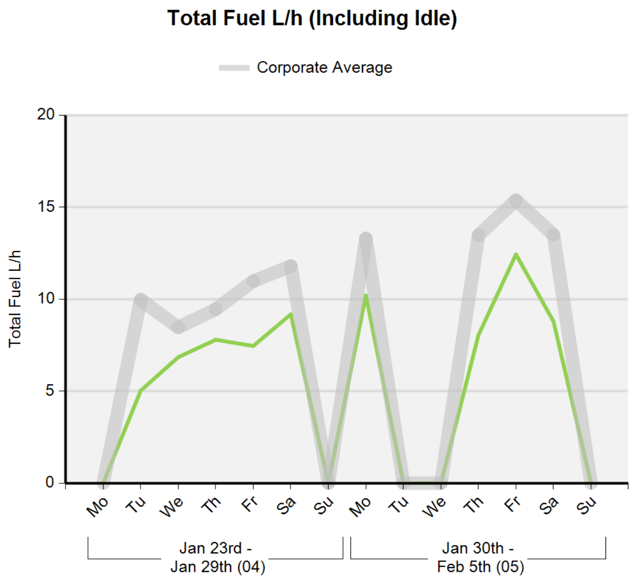


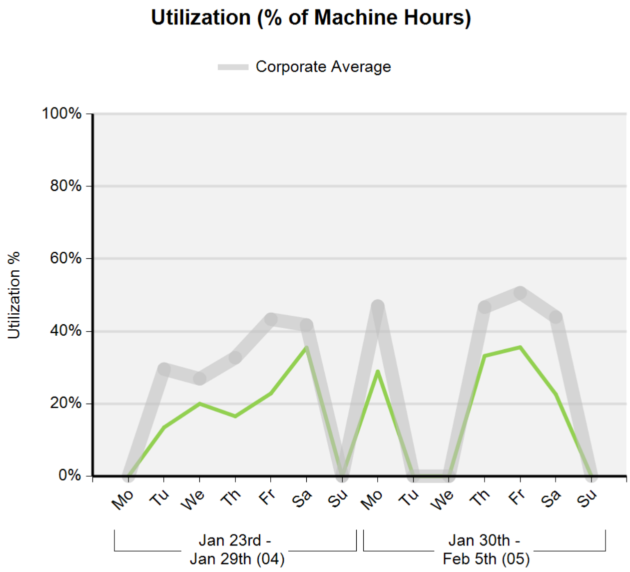
3. Machine: AFS 12-7339 (A40G340247) (Model: A40, Application: Other Building)

The following graphs shows you different aspects of fuel consumption.





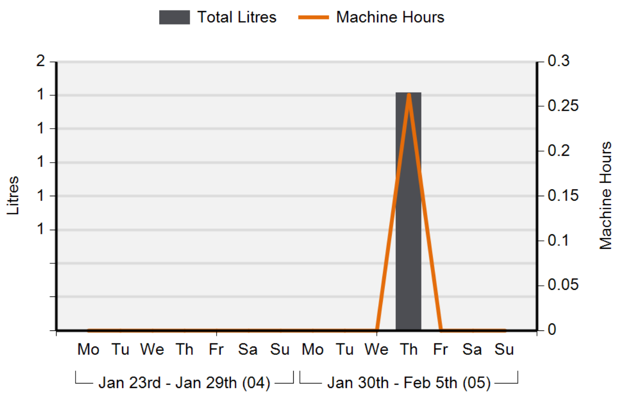




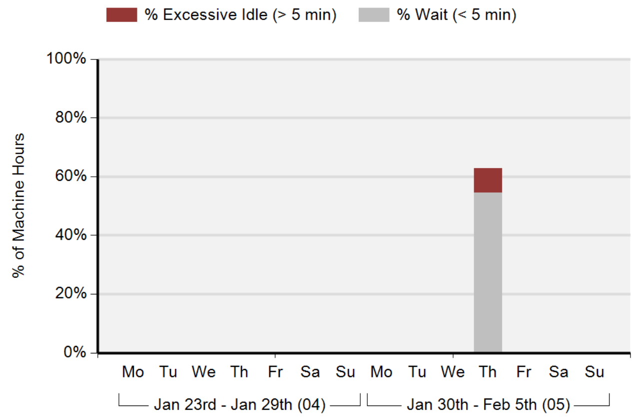
3. Machine: AFS21-0050 (C220E321043) (Model: EC220, Application: Other Building)

The following graphs shows you different aspects of fuel consumption.

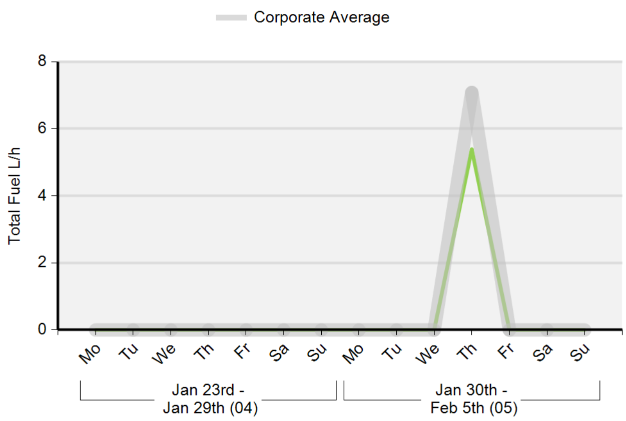
Total Fuel Consumption and Machine Hours



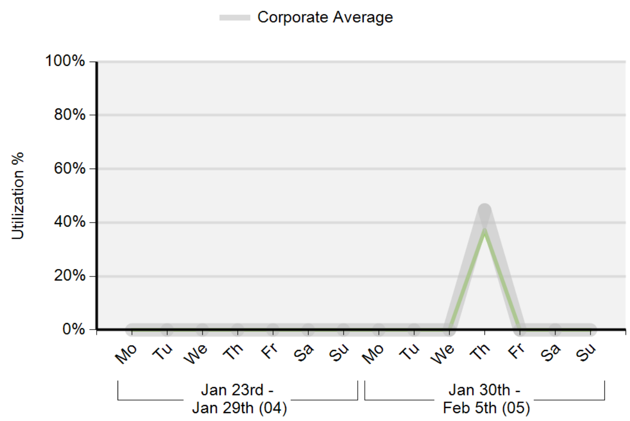
Idle



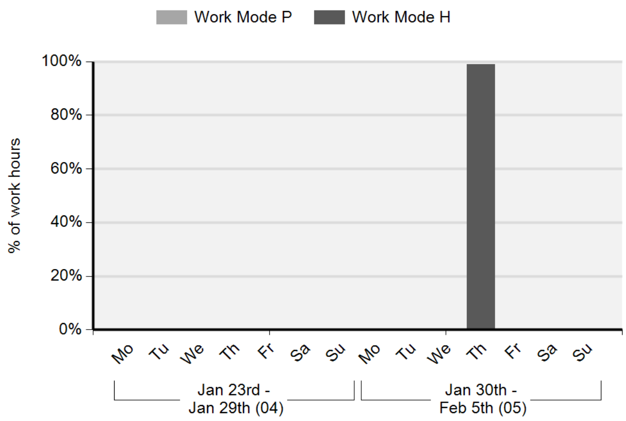
Total Fuel L/h (Including Idle)



Utilization (% of Machine Hours)



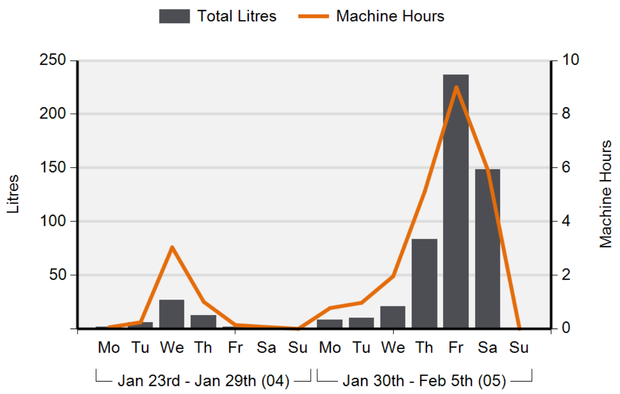
High Work Modes (Sum of H- and P-modes %)



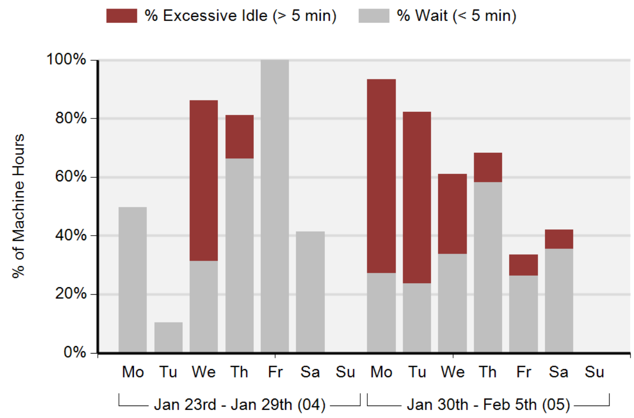
3. Machine: AFS21-0056 (C480E310531) (Model: EC480, Application: Other Building)

The following graphs shows you different aspects of fuel consumption.

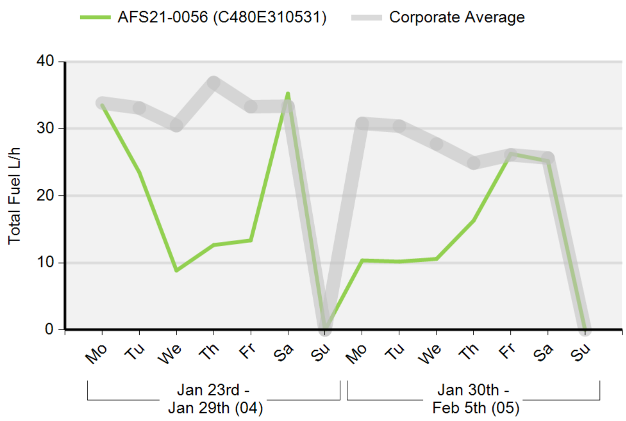
Total Fuel Consumption and Machine Hours



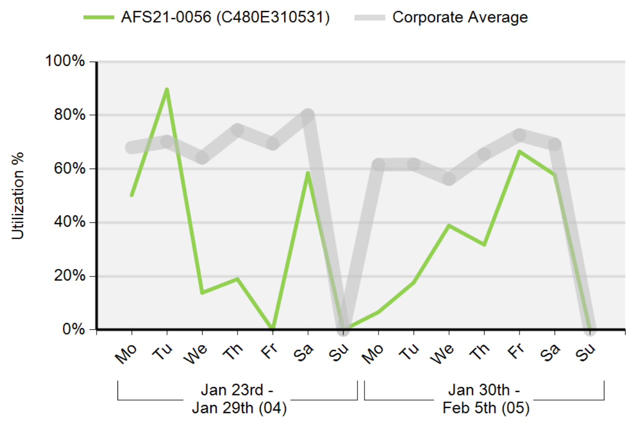
Idle



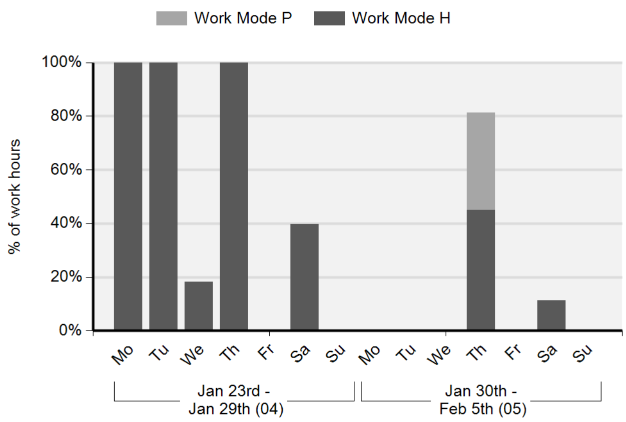
Total Fuel L/h (Including Idle)



Utilization (% of Machine Hours)

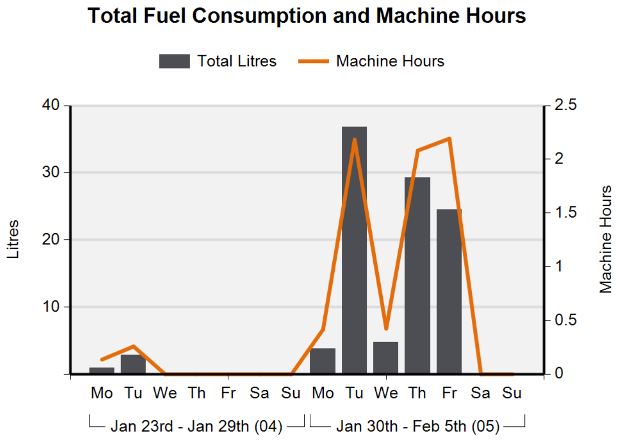


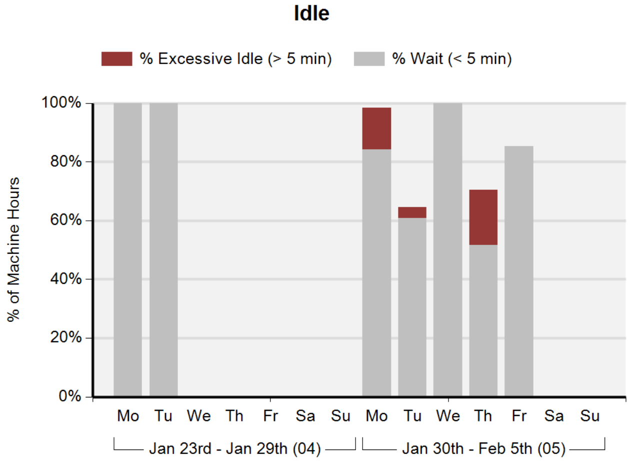
High Work Modes (Sum of H- and P-modes %)

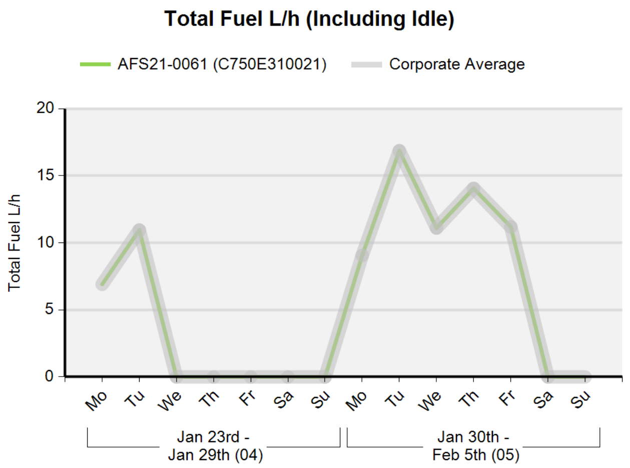


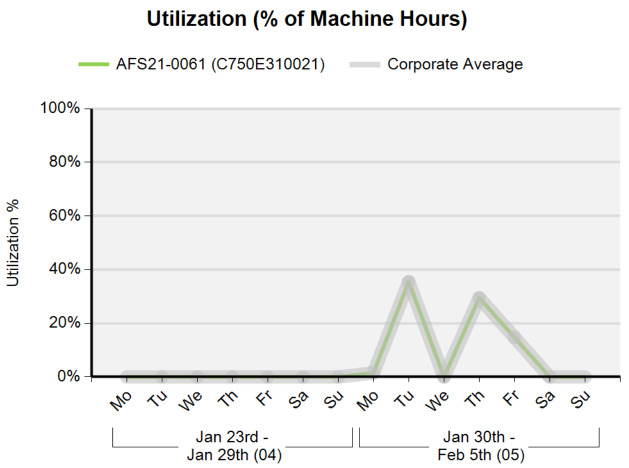
3. Machine: AFS21-0061 (C750E310021) (Model: EC750, Application: Other Building)

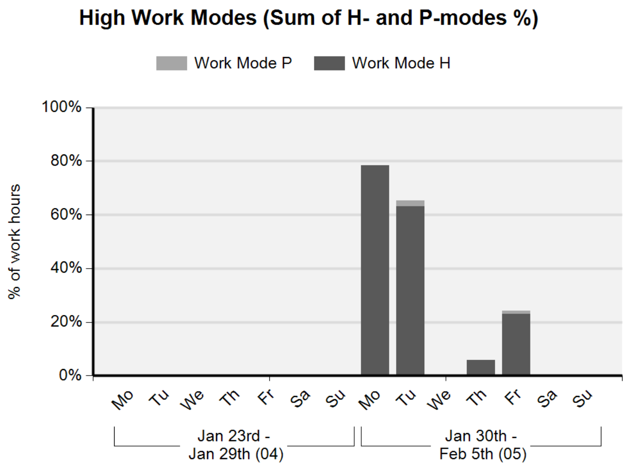
The following graphs shows you different aspects of fuel consumption.







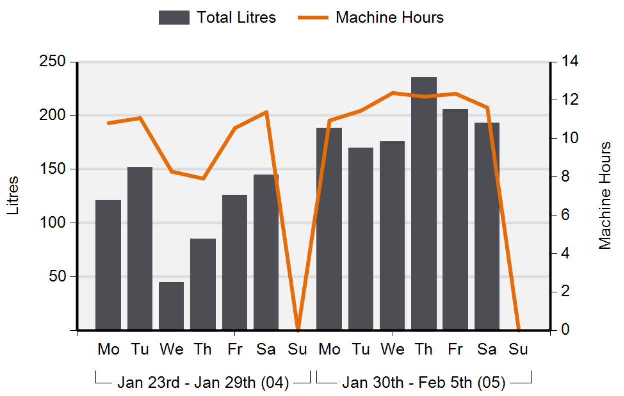




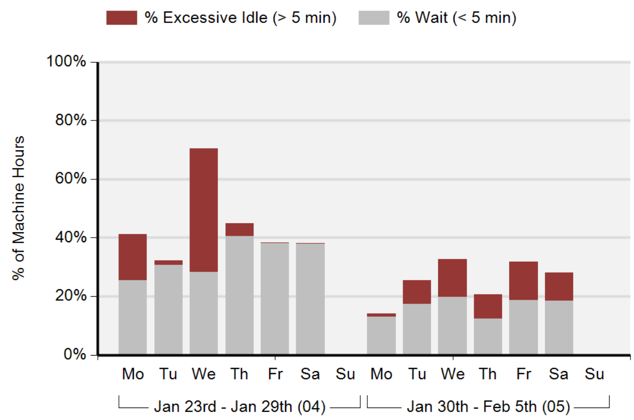
3. Machine: AFS 21-7145 (EC300210543) (Model: EC300, Application: Grain/Crop Handling/Silage making)

The following graphs shows you different aspects of fuel consumption.

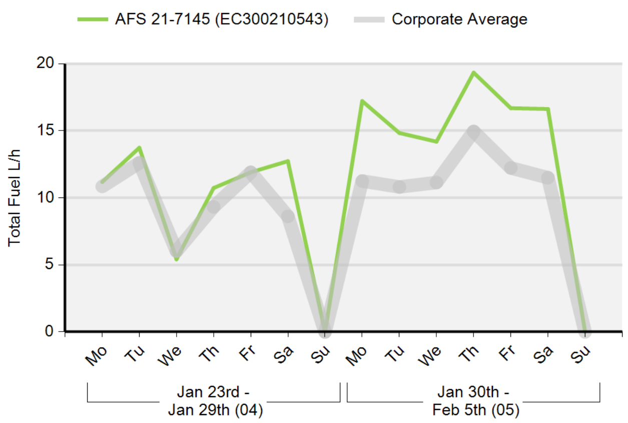
Total Fuel Consumption and Machine Hours



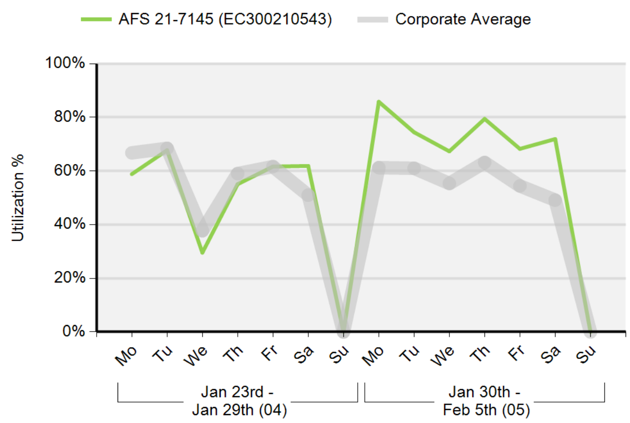
Idle



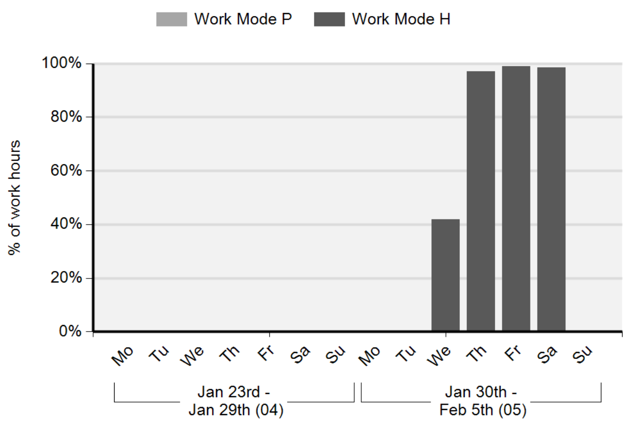
Total Fuel L/h (Including Idle)



Utilization (% of Machine Hours)

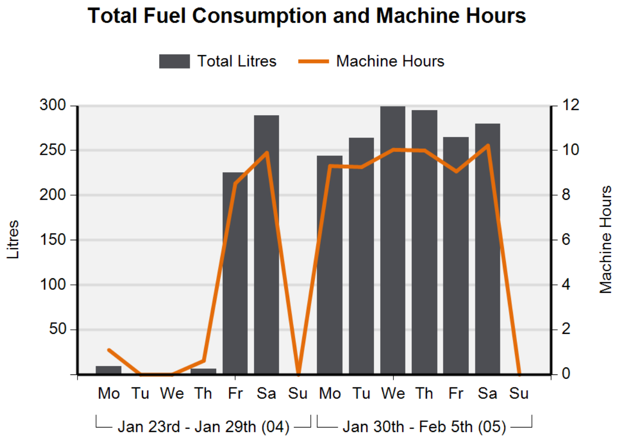


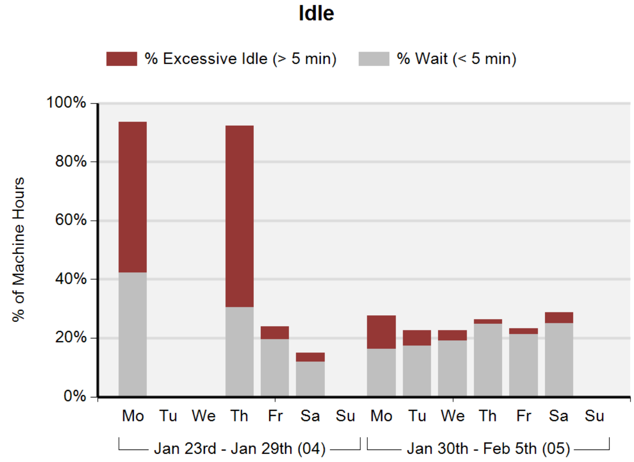
High Work Modes (Sum of H- and P-modes %)

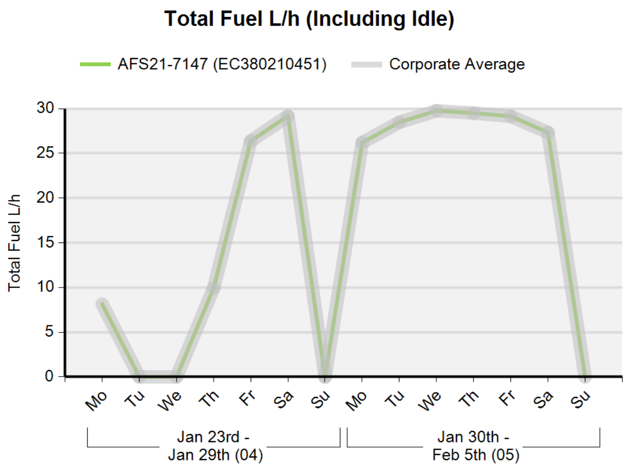


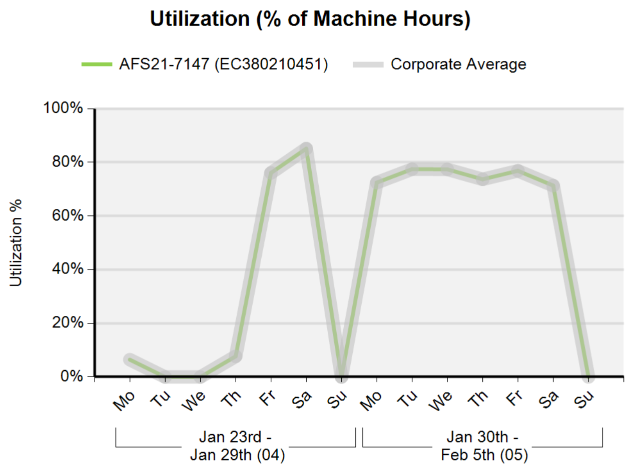
3. Machine: AFS21-7147 (EC380210451) (Model: EC380, Application: Grain/Crop Handling/Silage making)

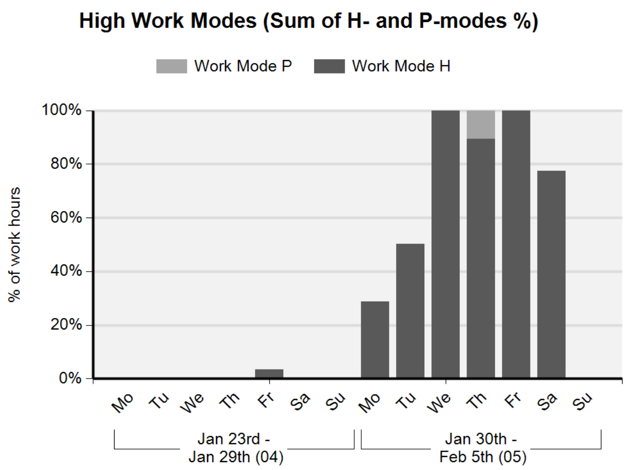
The following graphs shows you different aspects of fuel consumption.







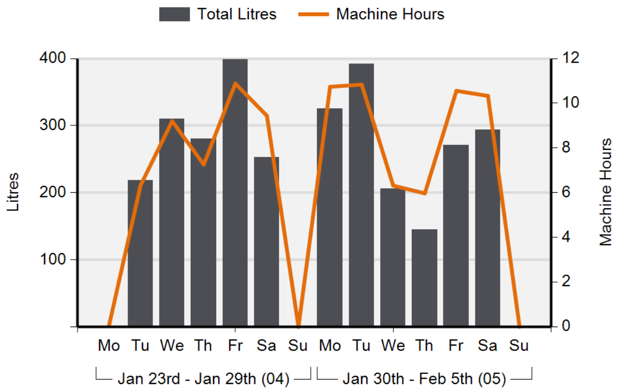




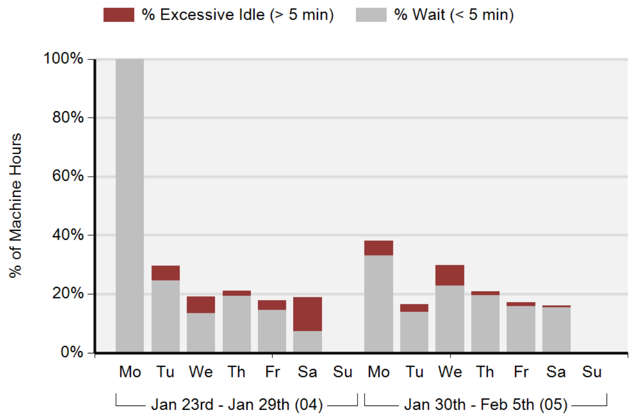
3. Machine: AFS21-7149 (EC480210305) (Model: EC480, Application: Other Building)

The following graphs shows you different aspects of fuel consumption.

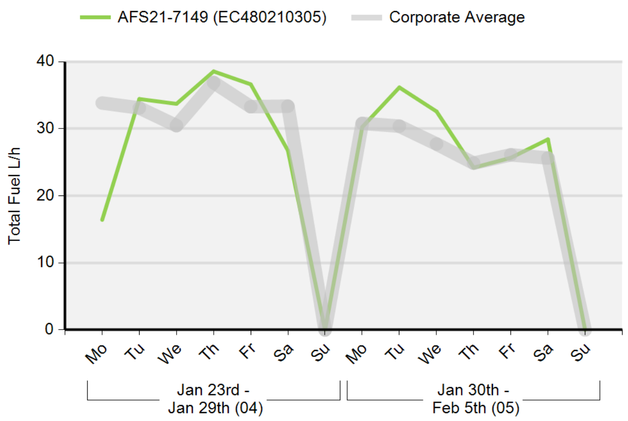
Total Fuel Consumption and Machine Hours



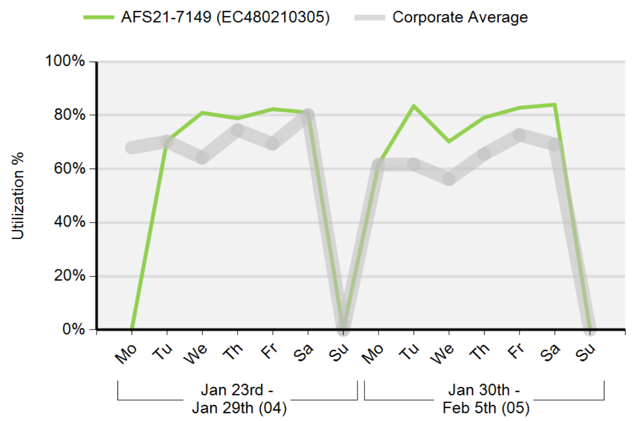
Idle



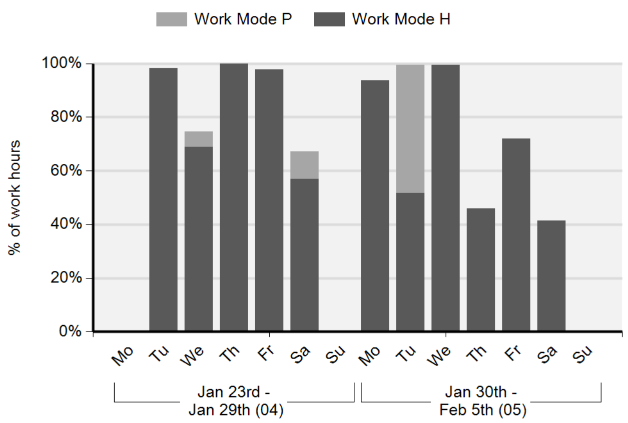
Total Fuel L/h (Including Idle)



Utilization (% of Machine Hours)



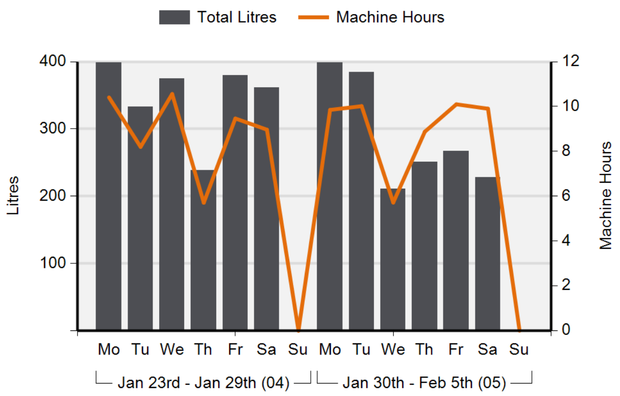
High Work Modes (Sum of H- and P-modes %)



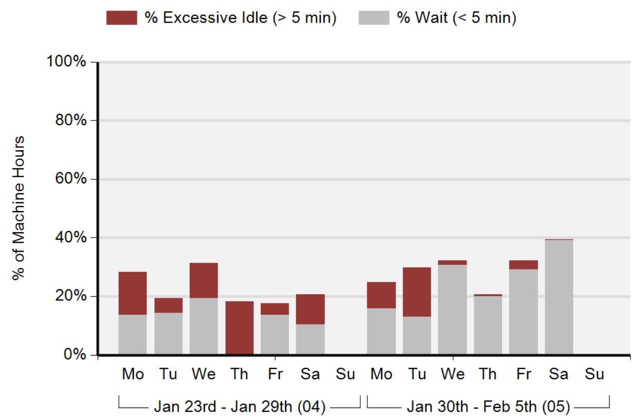
3. Machine: AFS21-7155 (EC480210413) (Model: EC480, Application: Other Building)

The following graphs shows you different aspects of fuel consumption.

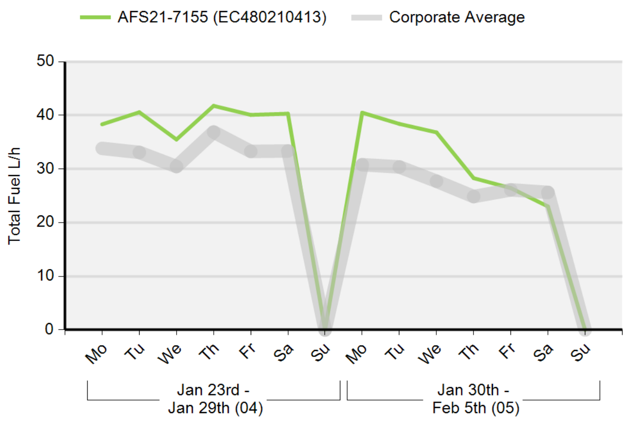
Total Fuel Consumption and Machine Hours



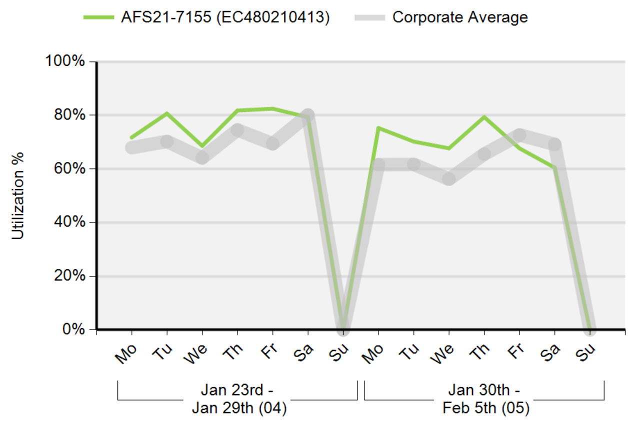
Idle



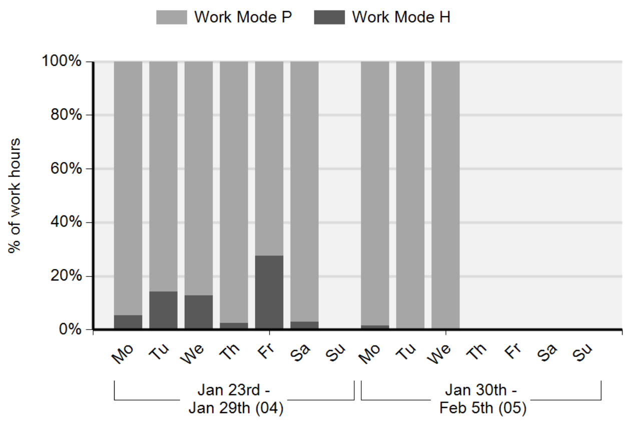
Total Fuel L/h (Including Idle)



Utilization (% of Machine Hours)



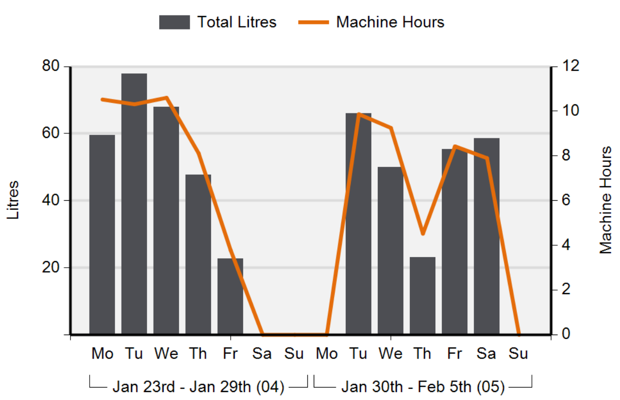
High Work Modes (Sum of H- and P-modes %)



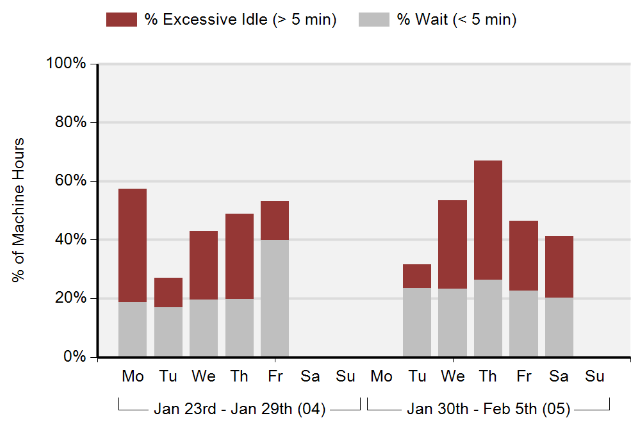
3. Machine: AFS 21-0029 (EW160220549) (Model: EW160, Application: Other Building)

The following graphs shows you different aspects of fuel consumption.

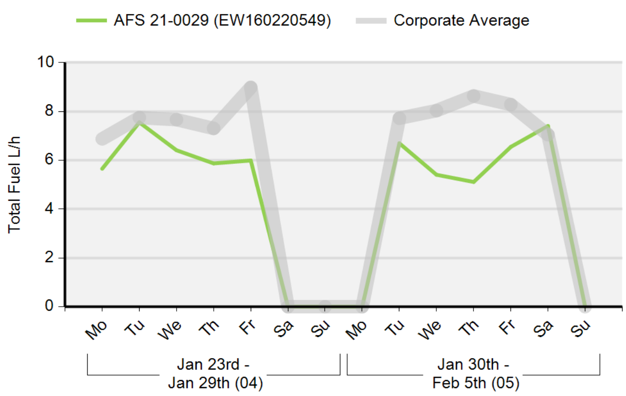
Total Fuel Consumption and Machine Hours



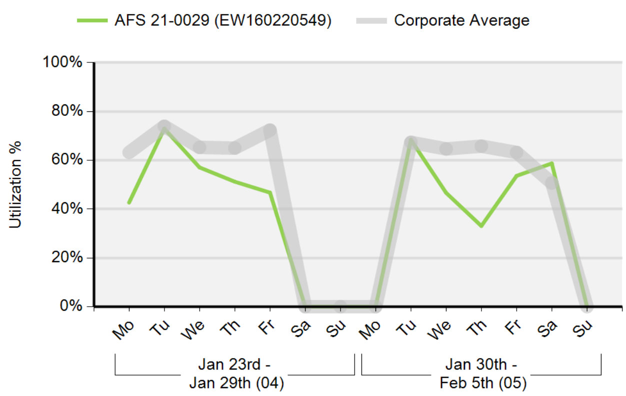
Idle



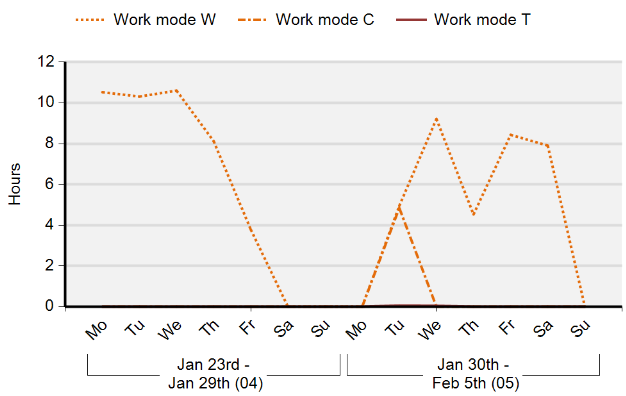
Total Fuel L/h (Including Idle)



Utilization (% of Machine Hours)



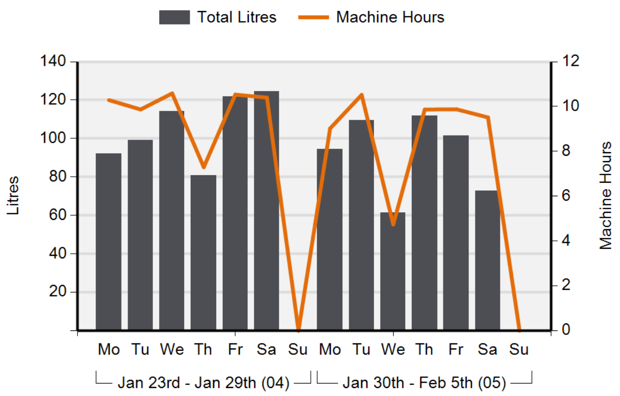
Hours in W-, C-, and T-modes (wheeled excavators)



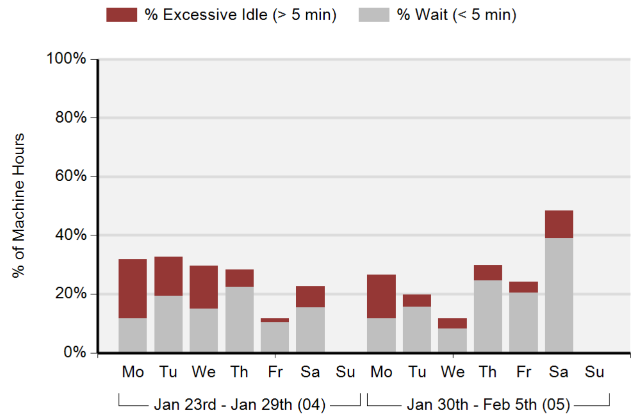
3. Machine: AFS 21-0040 (EW160221030) (Model: EW160, Application: Other Building)

The following graphs shows you different aspects of fuel consumption.

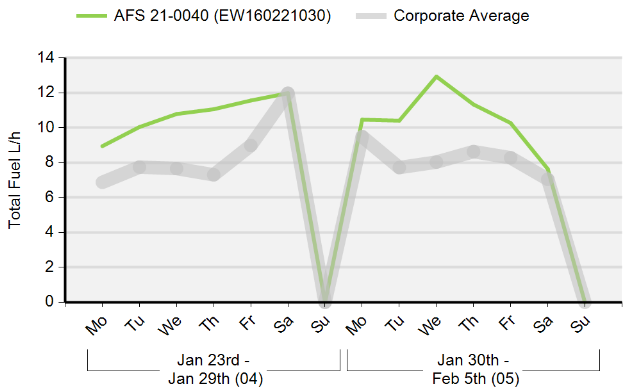
Total Fuel Consumption and Machine Hours



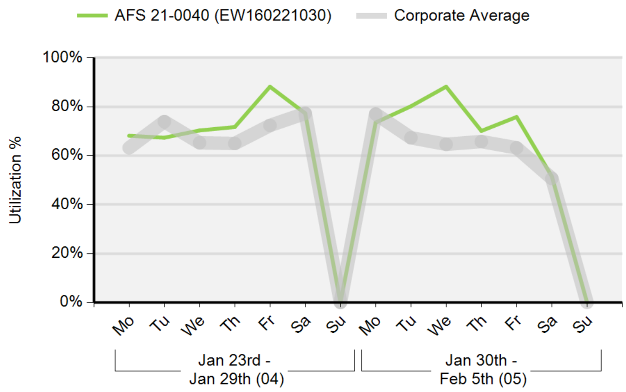
Idle



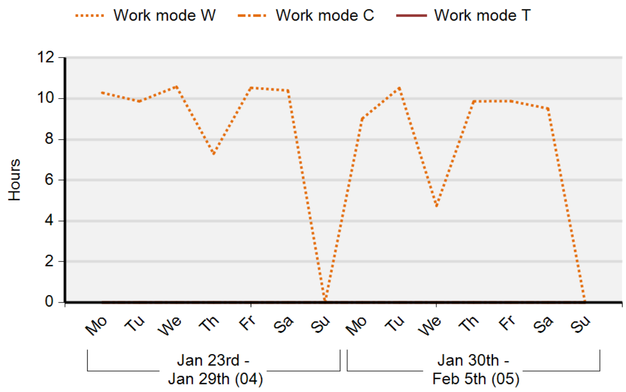
Total Fuel L/h (Including Idle)



Utilization (% of Machine Hours)

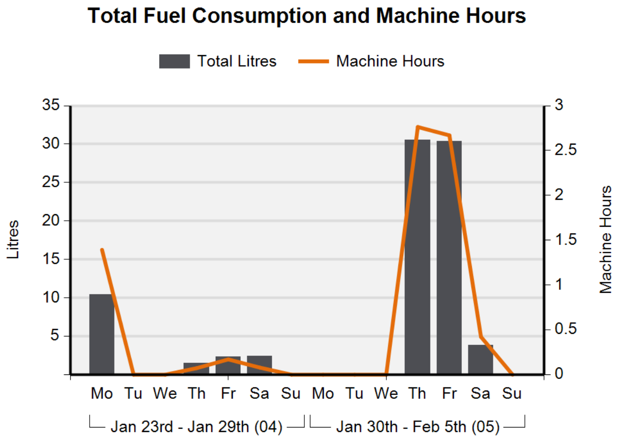


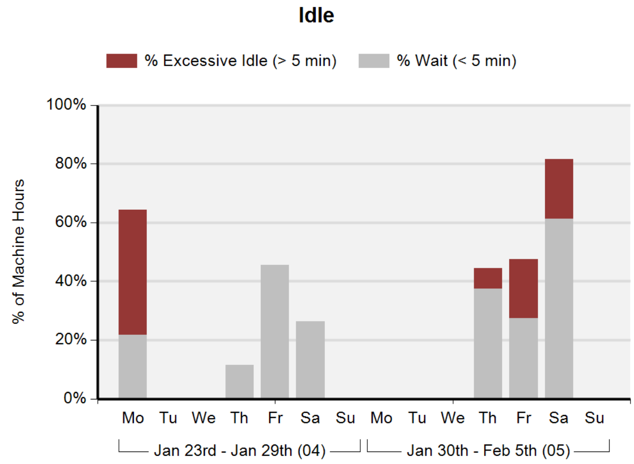
Hours in W-, C-, and T-modes (wheeled excavators)

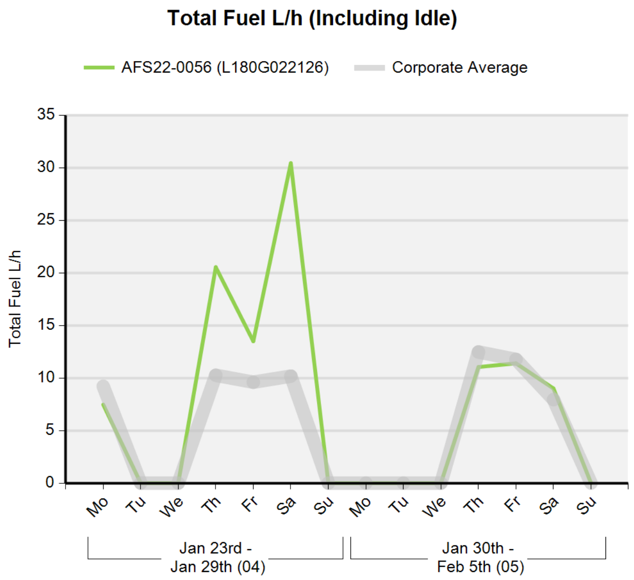


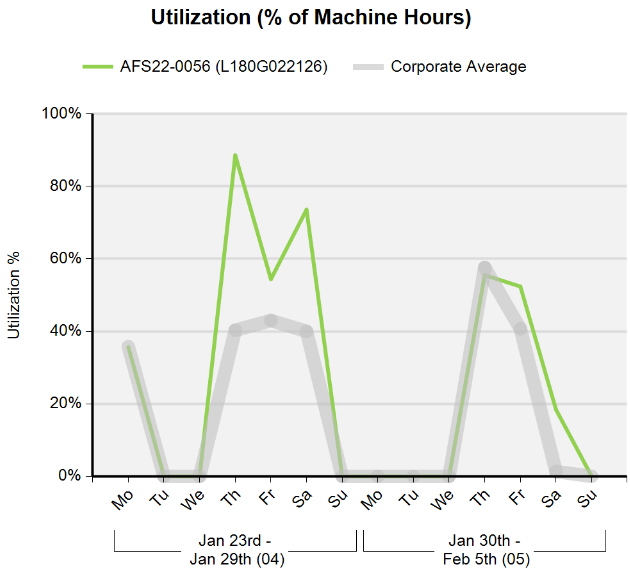
3. Machine: AFS22-0056 (L180G022126) (Model: L180, Application: Other Building)

The following graphs shows you different aspects of fuel consumption.





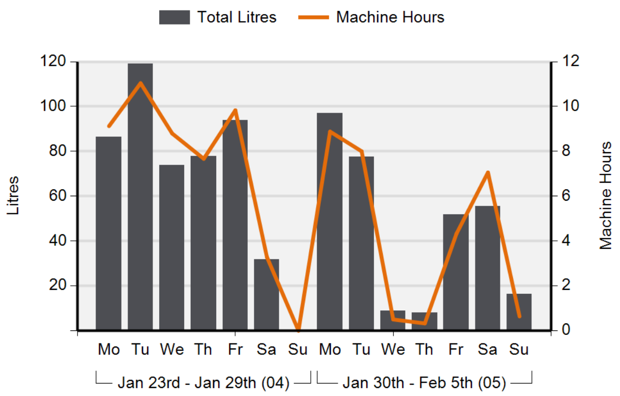




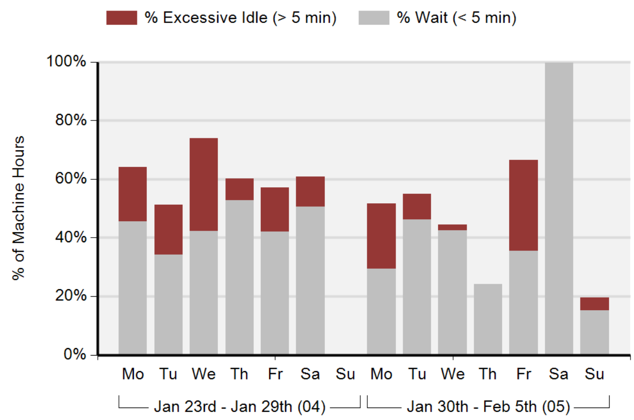
3. Machine: AFS 22-0063 (L180H003495) (Model: L180, Application: Other Building)

The following graphs shows you different aspects of fuel consumption.

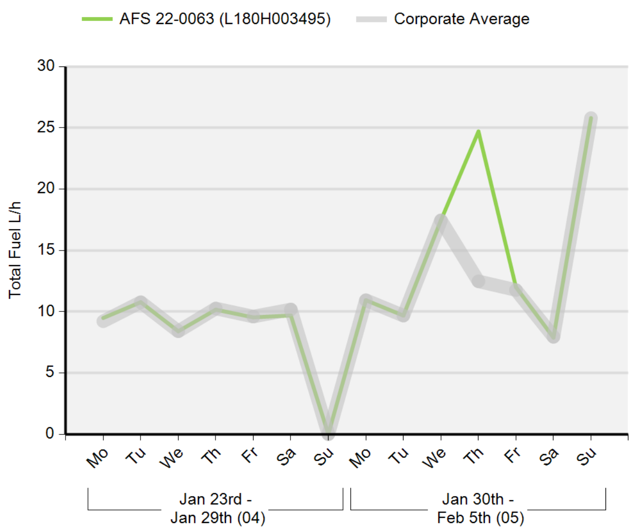
Total Fuel Consumption and Machine Hours



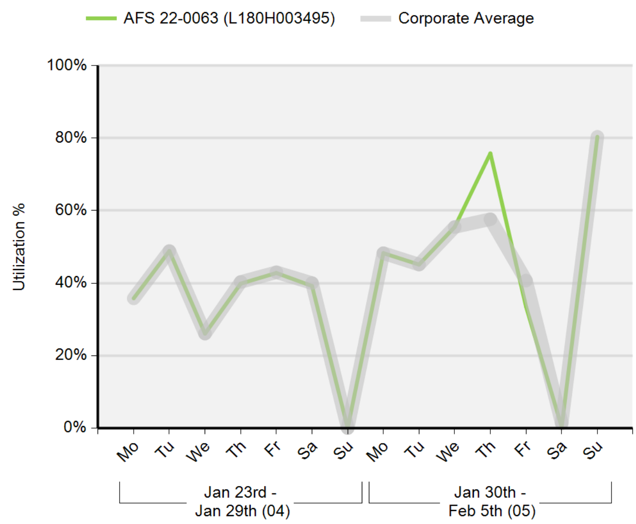
Idle



Total Fuel L/h (Including Idle)

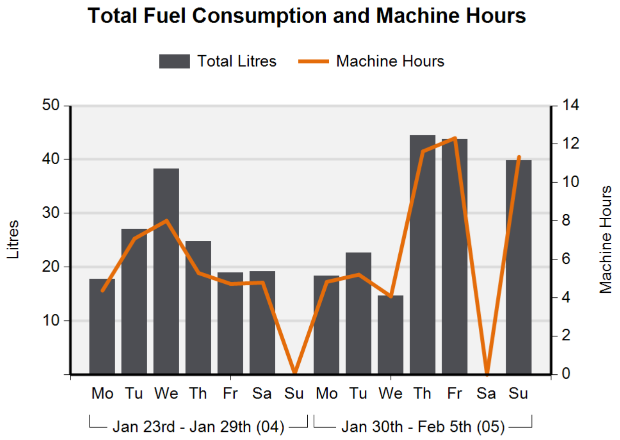


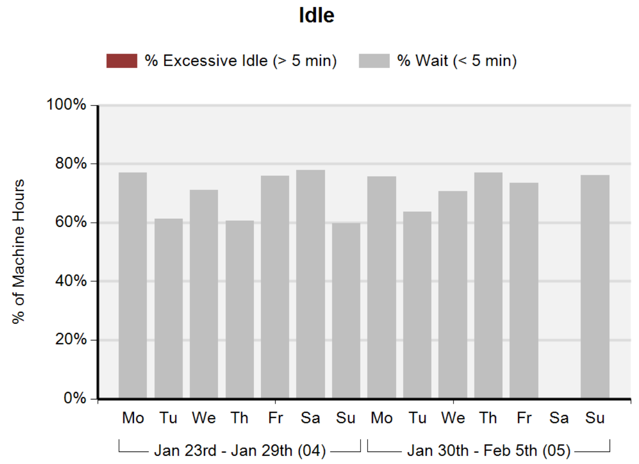
Utilization (% of Machine Hours)

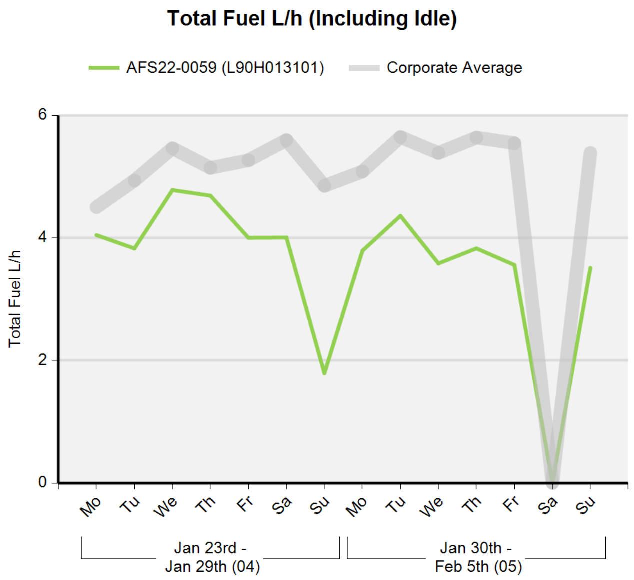


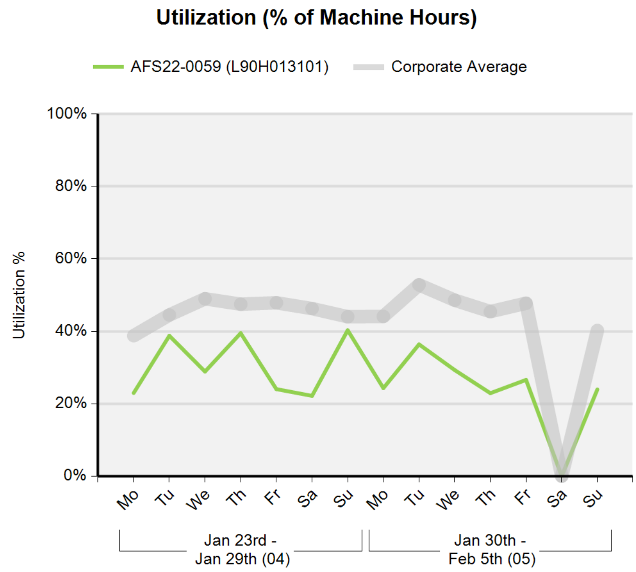
3. Machine: AFS22-0059 (L90H013101) (Model: L90, Application: Other Building)

The following graphs shows you different aspects of fuel consumption.



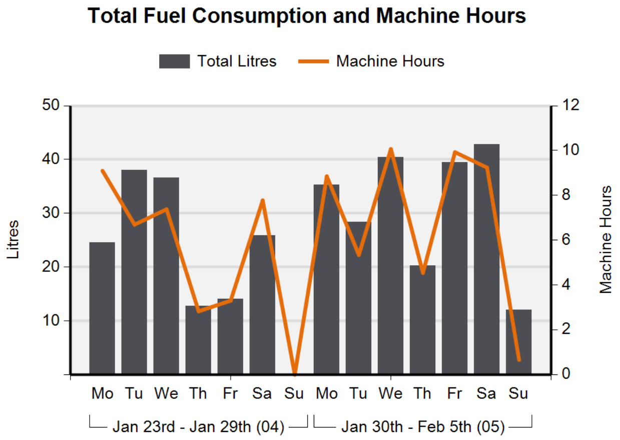


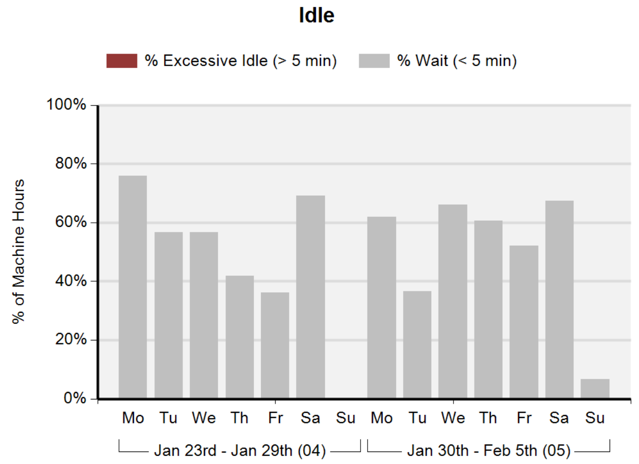


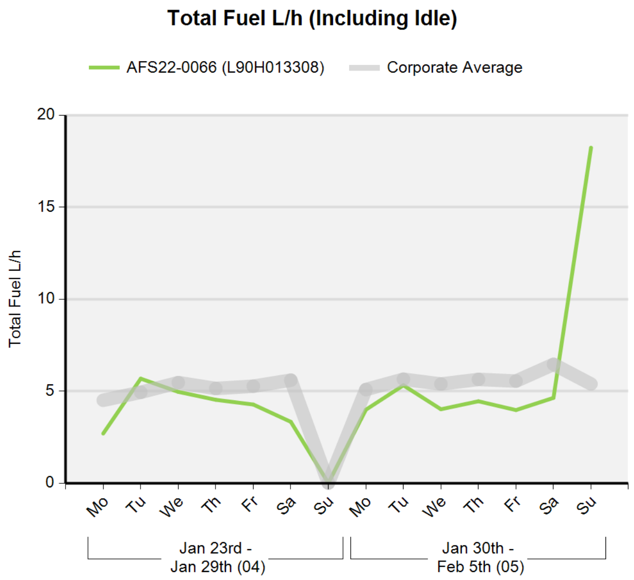


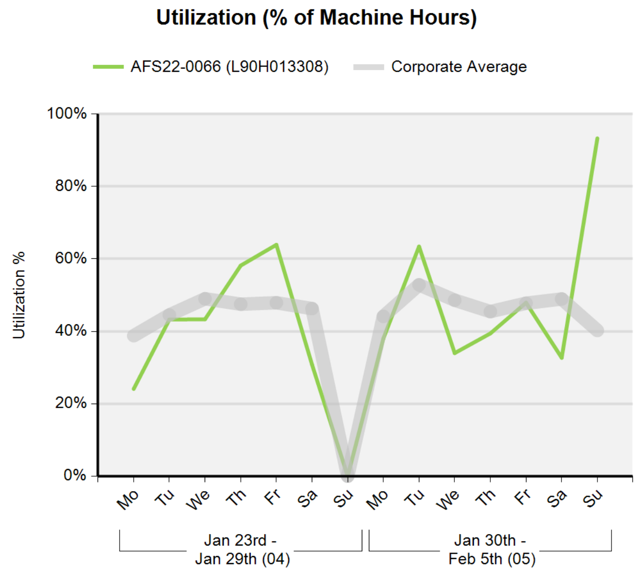
3. Machine: AFS22-0066 (L90H013308) (Model: L90, Application: Other Building)

The following graphs shows you different aspects of fuel consumption.



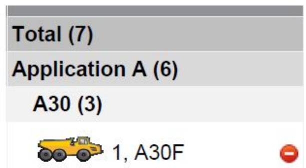
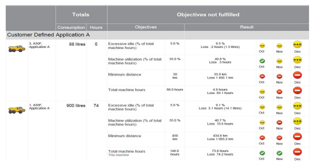






4. Help

Information concerning each section is presented below.

Section	Purpose	Example image
Dashboard	To see how you have performed compared to the objectives. If the needle is pointing up in a vertical line, you have exactly reached your objective. The aim is to stay in the green area. *Example to right: The performance is better compared to the objective.*	
Summary by Application	This time the grouping is made by machine application. Similar machines (based on model) that are working with the same job task/application are grouped together to best compare ‘like for like’ performance across the company. *Example to right: Seven machines are presented in the list, of which six of them are working with the job task “Application A” and three of them are of model A30.*	
Focus List	Up to eight different objectives can be defined on the machines with the help of the dealer, depending on the customer's situation. The system will initially state interim objectives for machines that are missing customer defined objectives. These are named “Interim objective: System generated” and that text will appear below the objective when applicable. The system states these interim objectives for each machine based upon historical average performance, and they could be used as guidelines when starting to define the objectives. Two levels for each objective are stated, taking “Excessive idle (> 5 min)” as an example.	

Objective:		Critical alert:	
	The machine is allowed to stand still max. 10% of total hours		It’s critical if the machine is standing still more than 15% of total hours.

The following objective can be used:

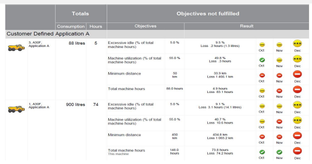
1	Overall l/h (idle included)	Measure how fuel efficient the machine has been in it's overall work cycle (total fuel including idle divided with hours)
2	L/h during work (idle excluded)	Measure how fuel efficient the machine has been operated while working (note, idle consumption not included, not the same as litres/hour above).
3	Utilization %	The % of time the machine has been in working mode compared to total machine hours.
4	Excessive idle (> 5 min)	The % of total hours. This measurement can be used to decrease the time spent standing still more than five minutes (excessive idle).
5	Machine hours	The total number of hours per week (Work hours + Waiting hours (machine standing still less than 5 min) + Excessive idle hours (machine standing still more than 5 min).
6	H-mode usage for crawler excavators (% of working hours)	Measure the % of the total working hours the machine has operated in H-mode. Some job tasks/situations require H-mode usage, but sometimes unnecessary use of this mode can cause excessive fuel consumption.
7	P-mode usage for crawler excavators (% of working hours)	Measure the % of the total working hours the machine has operated in P-mode. Some job tasks/situations require P-mode usage, but sometimes unnecessary use of this mode can cause excessive fuel consumption.

<table>
<tr><td></td><td>

8	Distance	Number of machine kilometres per week.

The machines that didn’t achieve their monthly objectives are presented in the focus list (both the ones with ‘yellow’ status and the ones with ‘red’ status).

Note: An objective is not stated for Wait (machine standing still less than 5 min).

Example to right: Two machines working with “Application A” failed to reach the desired level of performance for four objectives.
</td><td></td></tr>
<tr><td>Detailed Information per Machine</td><td>

The detailed information for each machine is presented. This information helps you to search for abnormal patterns causing the machine to miss its objectives. A daily view is presented to find out on which day the efficiency could be improved. The following efficiency measurements are presented:

- Total Fuel Consumption and Machine Hours
- Idle: Divided in to wait (< 5 min) and excessive idle (> 5 min)
- Total Fuel L/h (including idle)
- Utilization (% of Machine Hours)
</td><td></td></tr>
</table>

Information concerning the various definitions is presented below.

Total					
Work				**Idle**	
Machine utilized				Machine partly utilized	
Excavator	*Wheel loader*	*Articulated hauler*		*Wait*	*Excessive idle*
Attachment in use - and/or travel operation	Machine rpm > 850 and/or speed > 0,5 km/h	Transmission not in neutral		Machine standing still less than 5 minutes with engine at idle.	Machine standing still more than 5 minutes with engine at idle.

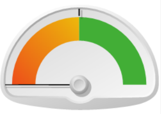
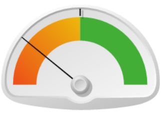
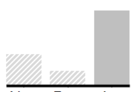
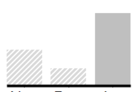
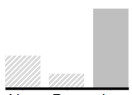
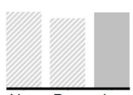
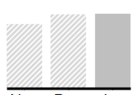
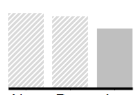
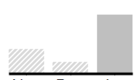
Disclaimers from CareTrack and MATRIS are valid for Efficient Operation Services. Volvo CE realizes that the complexity in which we are working can create unforeseen problems and that inaccuracy of data is possible. Therefore we kindly ask you to report any errors as soon as possible.

Volvo Construction Equipment

FUEL EFFICIENCY

This report includes all of your Volvo machines, by site and job task.

DEALER	CUSTOMER	REGION	SITE
VOLVO MASKIN AS	AF Gruppen Norge AS	AF Anlegg	Tvedestrand-Arendal Forbindelsen
CONTACT Marius Engström +47 92 69 69 25 marius.engstrom@volvo.com	CONTACT Tom Rainer Nilsen +4790547782 tom.rainer.nilsen@afgruppen.no	CONTACT	CONTACT
ISSUE DATE: 10th of Feb 2017	PERIOD: Jan. 2017	REPORT SCOPE: Machines operating on site - Tvedestrand-Arendal Forbindelsen	

	Total 24 Machines		Work Machine utilized		Idle Machine partly utilized		CO_2 Emissions
	Fuel Consumption	Hours	Fuel consumption during work	Utilization	Wait (< 5 min)	Excessive Idle (> 5 min)	
Jan. Results:	**23 393 Litres** 233 926 NOK	**1 821 Hours**	**19 245 Litres** 192 450 NOK	**46%** 835 Hours	**36%** 26 733 NOK	**18%** 14 743 NOK	**60.82 Tonnes CO_2**
Objective:	23 884 Litres 238 842 NOK	2 826 Hours	18 449 Litres 184 490 NOK	63% 1 178 Hours	27% 20 295 NOK	10% 7 020 NOK	62.10 Tonnes CO_2
Results compared to objectives:	 Below objective: 492 Litres 4 916 NOK	 Below objective: 1 005 Hours	 Above objective: 796 Litres 7 960 NOK	 Below objective: 17% 344 Hours	 Above objective: 9% 6 438 NOK	 Above objective: 8% 7 723 NOK	 Not exceeded: 1.28 Tonnes CO_2
Trend of actual figures:	 Nov Dec Jan Litres	 Nov Dec Jan Hours	 Nov Dec Jan Litres	 Nov Dec Jan %	 Nov Dec Jan %	 Nov Dec Jan %	 Nov Dec Jan Tonnes CO_2

2. Index

Note! When viewing this report in PDF, please use the bookmark tab to the left to jump between pages.

3. Summary by Application

The table shows efficiency data for individual machines, grouped by application.

	Total			Work Machine utilized			Idle Machine partly utilized		
	Hours	Ltrs	L/h	Utilization	Ltrs	L/h During work	Wait (< 5min) Hours	Excessive idle (> 5min) Hours	Sub-dealer
Total (24)	**1 821**	**23 393**	**12.8**	**46%**	**19 245**	**23.1**	**657**	**328**	
Other Building (20)	**1 518**	**17 939**	**11.8**	**43%**	**14 197**	**22.0**	**588**	**285**	
A40 (10)	**557**	**5 978**	**10.7**	**30%**	**4 041**	**23.9**	**252**	**136**	
AFS 12-7337 (A40G340190)	90	862	9.6	35%	612	19.2	39	20	
AFS 12-7336 (A40G340186)	108	990	9.2	29%	681	21.5	64	13	
AFS 12-7339 (A40G340247)	51	373	7.3	20%	222	21.5	25	16	
AFS12-7334 (A40F012291)	94	1 063	11.3	32%	678	22.2	45	19	
AFS 12-7338 (A40G340241)	12	67	5.5	7%	19	23.0	4	8	
AFS12-7332 (A40F012113)	11	73	6.7	6%	15	24.0	3	7	
AFS12-7330 (A40F011973)	6	65	10.0	15%	23	24.2	3	2	
AFS12-7333 (A40F012288)	44	516	11.8	28%	309	24.9	22	10	
AFS12-9901 (A40F012352)	29	267	9.2	17%	145	28.5	13	11	
AFS12-7331 (A40F012101)	111	1 703	15.3	41%	1 338	29.7	36	30	
EC480 (3)	**211**	**6 790**	**32.1**	**65%**	**6 226**	**45.2**	**41**	**33**	
AFS21-0056 (C480E310531)	13	139	10.9	18%	60	27.1	5	5	
AFS21-7149 (EC480210305)	88	2 789	31.7	72%	2 598	41.2	17	8	
AFS21-7155 (EC480210413)	111	3 862	34.8	65%	3 567	49.2	18	20	
EC750 (1)	**3**	**45**	**14.9**	**26%**	**27**	**34.4**	**2**	**0**	
AFS21-0061 (C750E310021)	3	45	14.9	26%	27	34.4	2	0	
EW160 (2)	**329**	**2 571**	**7.8**	**59%**	**2 311**	**11.9**	**63**	**72**	
AFS 21-0029 (EW160220549)	149	916	6.1	49%	773	10.6	35	42	
AFS 21-0040 (EW160221030)	180	1 655	9.2	68%	1 538	12.6	28	30	
L180 (2)	**154**	**1 528**	**9.9**	**35%**	**894**	**16.7**	**57**	**44**	
AFS22-0056 (L180G022126)	20	139	7.0	11%	31	14.2	4	14	

	Total			Work Machine utilized			Idle Machine partly utilized		
	Hours	Ltrs	L/h	Utilization	Ltrs	L/h During work	Wait (< 5min) Hours	Excessive idle (> 5min) Hours	Sub-dealer
Total (24)	**1 821**	**23 393**	**12.8**	**46%**	**19 245**	**23.1**	**657**	**328**	
AFS 22-0063 (L180H003495)	134	1 389	10.3	38%	863	16.9	53	30	
L90 (2)	**263**	**1 027**	**3.9**	**34%**	**699**	**7.8**	**173**	**0**	
AFS22-0059 (L90H013101)	142	534	3.8	33%	362	7.8	96	0	
AFS22-0066 (L90H013308)	120	493	4.1	36%	337	7.9	78	0	
Grain/Crop Handling/Silage making (3)	**296**	**5 424**	**18.3**	**64%**	**5 037**	**26.7**	**66**	**41**	
A40 (1)	**5**	**23**	**4.9**	**14%**	**7**	**11.1**	**2**	**2**	
Rental (A40G340041)	5	23	4.9	14%	7	11.1	2	2	
EC300 (1)	**179**	**2 248**	**12.6**	**61%**	**2 121**	**19.5**	**46**	**25**	
AFS 21-7145 (EC300210543)	179	2 248	12.6	61%	2 121	19.5	46	25	
EC380 (1)	**113**	**3 153**	**28.0**	**70%**	**2 908**	**36.8**	**19**	**15**	
AFS21-7147 (EC380210451)	113	3 153	28.0	70%	2 908	36.8	19	15	
General Road Construction (1)	**6**	**29**	**4.5**	**17%**	**11**	**10.3**	**3**	**2**	
EC300 (1)	**6**	**29**	**4.5**	**17%**	**11**	**10.3**	**3**	**2**	
AFS21-0055 (C300E311194)	6	29	4.5	17%	11	10.3	3	2	

4. Focus List

The table only shows machines where the results during the period does not reach objective levels.
Machines in yellow status are between objective level and red level.

Machines not reaching their objectives, in the current month, led to a deviation compared to the objectives amounting to:

Total fuel l/h (including idle):	3 166 Litres	
Working fuel l/h (excluding idle):	1 994 Litres	
Minimum distance:	8 236 Km	
Excessive idle (% of total machine hours):	174 Hours	(782 Litres)
Total machine hours:	1 379 Hours	
Machine utilization (% of total machine hours):	362 Hours	
H-mode usage for EXC (% of working hours):	1 051 Litres	
P-mode usage for EXC (% of working hours):	1 277 Litres	

		Total		Objectives not fulfilled					
		Consumption	Hours	Objectives		Result			
General Road Construction									
	AFS21-0055 (C300E311194), General Road Construction	29 Litres	6	Excessive idle (% of total machine hours) Interim objective: System generated	10.0 %	35.9 % Loss 1.7 Hours (5 Litres)	Nov	Dec	Jan
				H-mode usage for EXC (% of working hours) Interim objective: System generated	5.0 %	10.8 % Loss - 1.1 Litres	Nov	Dec	Jan
				Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	17.0 % Loss 2.8 Hours	Nov	Dec	Jan
				Total fuel l/h (including idle) Interim objective: System generated	4.3 l/h	4.5 l/h Loss 1.5 Litres	Nov	Dec	Jan
				Total machine hours Interim objective: System generated	15.1 Hours	6.5 Hours Loss 8.6 Hours	Nov	Dec	Jan
				Working fuel l/h (excluding idle) Interim objective: System generated	9.8 l/h	10.3 l/h Loss .6 Litres	Nov	Dec	Jan
Grain/Crop Handling/Silage making									
	AFS21-7147 (EC380210451), Grain/Crop Handling/Silage making	3 153 Litres	113	Excessive idle (% of total machine hours) Interim objective: System generated	10.0 %	13.1 % Loss 3.5 Hours (26 Litres)	Nov	Dec	Jan
				H-mode usage for EXC (% of working hours) Interim objective: System generated	5.0 %	10.9 % Loss 40.2 Litres	Nov	Dec	Jan
				P-mode usage for EXC (% of working hours) Interim objective: System generated	1.0 %	55.9 % Loss 394.3 Litres	Nov	Dec	Jan
				Total fuel l/h (including idle) Interim objective: System generated	11.4 l/h	28.0 l/h Loss 1 874.1 Litres	Nov	Dec	Jan
				Working fuel l/h (excluding idle) Interim objective: System generated	28.2 l/h	36.8 l/h Loss 674.8 Litres	Nov	Dec	Jan

Machine	Total		Objectives not fulfilled					
	Consumption	Hours	Objectives		Result			
AFS 21-7145 (EC300210543), Grain/Crop Handling/Silage making	2 248 Litres	179	Excessive idle (% of total machine hours) Interim objective: System generated	10.0 %	13.8 % Loss 6.8 Hours (12.1 Litres)	Nov	Dec	Jan
			H-mode usage for EXC (% of working hours) Interim objective: System generated	5.0 %	34.3 % Loss 189.8 Litres	Nov	Dec	Jan
			Total fuel l/h (including idle) Interim objective: System generated	9.3 l/h	12.6 l/h Loss 585.3 Litres	Nov	Dec	Jan
			Working fuel l/h (excluding idle) Interim objective: System generated	15.7 l/h	19.5 l/h Loss 417.3 Litres	Nov	Dec	Jan
Rental (A40G340041), Grain/Crop Handling/Silage making	23 Litres	5	Excessive idle (% of total machine hours) Interim objective: System generated	10.0 %	41.0 % Loss 1.5 Hours (5.5 Litres)	Nov	Dec	Jan
			Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	14.1 % Loss 2.2 Hours	Nov	Dec	Jan
			Minimum distance Interim objective: System generated	287.4 Km	2.2 km Loss 285.2 Km	Nov	Dec	Jan
			Total machine hours Interim objective: System generated	70.6 Hours	4.7 Hours Loss 65.9 Hours	Nov	Dec	Jan
Other Building								
AFS12-7330 (A40F011973), Other Building	65 Litres	6	Excessive idle (% of total machine hours) Interim objective: System generated	10.0 %	36.8 % Loss 1.7 Hours (11.6 Litres)	Nov	Dec	Jan
			Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	14.6 % Loss 2.9 Hours	Nov	Dec	Jan
			Minimum distance Interim objective: System generated	836.8 Km	7.8 km Loss 828.9 Km	Nov	Dec	Jan
			Total machine hours Interim objective: System generated	174.0 Hours	6.5 Hours Loss 167.6 Hours	Nov	Dec	Jan
AFS12-7331 (A40F012101), Other Building	1 703 Litres	111	Excessive idle (% of total machine hours) Interim objective: System generated	10.0 %	27.3 % Loss 19.3 Hours (97.9 Litres)	Nov	Dec	Jan
			Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	40.5 % Loss 21.6 Hours	Nov	Dec	Jan
			Minimum distance Interim objective: System generated	713.4 Km	460.1 km Loss 253.3 Km	Nov	Dec	Jan
			Total machine hours Interim objective: System generated	158.4 Hours	111.2 Hours Loss 47.2 Hours	Nov	Dec	Jan
AFS12-7332 (A40F012113), Other Building	73 Litres	11	Excessive idle (% of total machine hours) Interim objective: System generated	10.0 %	67.4 % Loss 6.2 Hours (34.7 Litres)	Nov	Dec	Jan
			Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	5.6 % Loss 5.9 Hours	Nov	Dec	Jan
			Minimum distance Interim objective: System generated	1,265.2 Km	4.1 km Loss 1 261.1 Km	Nov	Dec	Jan
			Total machine hours Interim objective: System generated	181.2 Hours	10.8 Hours Loss 170.4 Hours	Nov	Dec	Jan

	Total		Objectives not fulfilled					
	Consumption	Hours	Objectives		Result			
AFS12-7333 (A40F012288), Other Building	516 Litres	44	Excessive idle (% of total machine hours) Interim objective: System generated	10.0 %	22.3 % Loss 5.3 Hours (35.4 Litres)	Nov	Dec	Jan
			Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	28.5 % Loss 13.7 Hours	Nov	Dec	Jan
			Minimum distance Interim objective: System generated	686.2 Km	88.4 km Loss 597.8 Km	Nov	Dec	Jan
			Total machine hours Interim objective: System generated	166.5 Hours	43.6 Hours Loss 123 Hours	Nov	Dec	Jan
			Working fuel l/h (excluding idle) Interim objective: System generated	24.1 l/h	24.9 l/h Loss 10.4 Litres	Nov	Dec	Jan
AFS12-7334 (A40F012291), Other Building	1 063 Litres	94	Excessive idle (% of total machine hours) Interim objective: System generated	10.0 %	19.7 % Loss 9.2 Hours (53.9 Litres)	Nov	Dec	Jan
			Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	32.3 % Loss 26.1 Hours	Nov	Dec	Jan
			Minimum distance Interim objective: System generated	1,129.2 Km	236.1 km Loss 893.1 Km	Nov	Dec	Jan
			Total machine hours Interim objective: System generated	180.1 Hours	94.3 Hours Loss 85.8 Hours	Nov	Dec	Jan
AFS12-9901 (A40F012352), Other Building	267 Litres	29	Excessive idle (% of total machine hours) Interim objective: System generated	10.0 %	38.4 % Loss 8.3 Hours (40.2 Litres)	Nov	Dec	Jan
			Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	17.4 % Loss 12.4 Hours	Nov	Dec	Jan
			Minimum distance Interim objective: System generated	123.9 Km	45.1 km Loss 78.9 Km	Nov	Dec	Jan
			Total machine hours Interim objective: System generated	64.1 Hours	29.1 Hours Loss 35 Hours	Nov	Dec	Jan
			Working fuel l/h (excluding idle) Interim objective: System generated	27.9 l/h	28.5 l/h Loss 3.3 Litres	Nov	Dec	Jan
AFS22-0059 (L90H013101), Other Building	534 Litres	142	Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	32.8 % Loss 38.7 Hours	Nov	Dec	Jan
			Total fuel l/h (including idle) Interim objective: System generated	3.3 l/h	3.8 l/h Loss 65.2 Litres	Nov	Dec	Jan
			Working fuel l/h (excluding idle) Interim objective: System generated	4.7 l/h	7.8 l/h Loss 142.4 Litres	Nov	Dec	Jan
AFS22-0066 (L90H013308), Other Building	493 Litres	120	Machine utilization (% of total machine hours) Interim objective: System generated	72.7 %	35.5 % Loss 44.8 Hours	Nov	Dec	Jan
			Minimum distance Interim objective: System generated	1,053.6 Km	310.0 km Loss 743.6 Km	Nov	Dec	Jan
			Total machine hours Interim objective: System generated	183.6 Hours	120.5 Hours Loss 63.1 Hours	Nov	Dec	Jan
AFS21-7149 (EC480210305), Other Building	2 789 Litres	88	H-mode usage for EXC (% of working hours) Interim objective: System generated	5.0 %	81.1 % Loss 761.9 Litres	Nov	Dec	Jan

	Total		Objectives not fulfilled					
	Consumption	Hours	Objectives		Result			
AFS21-7149 (EC480210305), Other Building	2 789 Litres	88	Machine utilization (% of total machine hours) Interim objective: System generated	78.8 %	71.7 % Loss 6.2 Hours	Nov	Dec	Jan
			P-mode usage for EXC (% of working hours) Interim objective: System generated	1.0 %	9.2 % Loss 94.8 Litres	Nov	Dec	Jan
			Total machine hours Interim objective: System generated	162.7 Hours	87.8 Hours Loss 74.9 Hours	Nov	Dec	Jan
			Working fuel l/h (excluding idle) Interim objective: System generated	40.8 l/h	41.2 l/h Loss 27.5 Litres	Nov	Dec	Jan
AFS21-7155 (EC480210413), Other Building	3 862 Litres	111	Excessive idle (% of total machine hours) Interim objective: System generated	10.0 %	18.0 % Loss 8.9 Hours (68.3 Litres)	Nov	Dec	Jan
			H-mode usage for EXC (% of working hours) Interim objective: System generated	5.0 %	13.2 % Loss 60.4 Litres	Nov	Dec	Jan
			Machine utilization (% of total machine hours) Interim objective: System generated	70.0 %	65.3 % Loss 5.2 Hours	Nov	Dec	Jan
			P-mode usage for EXC (% of working hours) Interim objective: System generated	1.0 %	86.5 % Loss 787.4 Litres	Nov	Dec	Jan
			Total fuel l/h (including idle) Interim objective: System generated	30.8 l/h	34.8 l/h Loss 445.5 Litres	Nov	Dec	Jan
			Total machine hours Interim objective: System generated	148.1 Hours	110.9 Hours Loss 37.2 Hours	Nov	Dec	Jan
			Working fuel l/h (excluding idle) Interim objective: System generated	43.4 l/h	49.2 l/h Loss 418.9 Litres	Nov	Dec	Jan
AFS 21-0029 (EW160220549) , Other Building	916 Litres	149	Excessive idle (% of total machine hours) Interim objective: System generated	10.0 %	28.1 % Loss 26.9 Hours (49.7 Litres)	Nov	Dec	Jan
			Machine utilization (% of total machine hours) Interim objective: System generated	70.6 %	48.7 % Loss 32.7 Hours	Nov	Dec	Jan
AFS 21-0040 (EW160221030) , Other Building	1 655 Litres	180	Excessive idle (% of total machine hours) Interim objective: System generated	10.0 %	16.7 % Loss 12 Hours (23.5 Litres)	Nov	Dec	Jan
			Machine utilization (% of total machine hours) Interim objective: System generated	78.0 %	67.7 % Loss 18.6 Hours	Nov	Dec	Jan
			Total fuel l/h (including idle) Interim objective: System generated	8.2 l/h	9.2 l/h Loss 183 Litres	Nov	Dec	Jan
			Working fuel l/h (excluding idle) Interim objective: System generated	10.3 l/h	12.6 l/h Loss 288.4 Litres	Nov	Dec	Jan
AFS22-0056 (L180G022126), Other Building	139 Litres	20	Excessive idle (% of total machine hours) Interim objective: System generated	10.0 %	70.8 % Loss 12.1 Hours (72.9 Litres)	Nov	Dec	Jan
			Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	11.0 % Loss 9.7 Hours	Nov	Dec	Jan
			Minimum distance Interim objective: System generated	299.7 Km	6.4 km Loss 293.3 Km	Nov	Dec	Jan
			Total machine hours Interim objective: System generated	117.4 Hours	19.8 Hours Loss 97.5 Hours	Nov	Dec	Jan

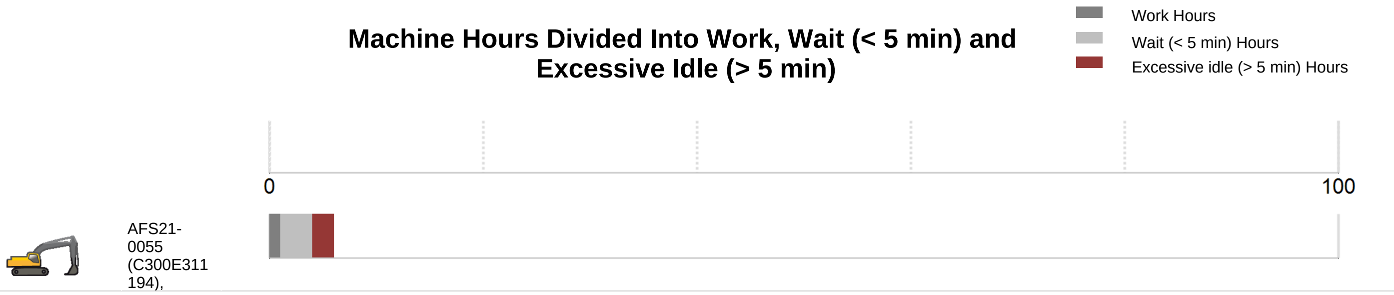
	Total		Objectives not fulfilled					
	Consumption	Hours	Objectives		Result			
AFS21-0061 (C750E310021), Other Building	45 Litres	3	H-mode usage for EXC (% of working hours) Interim objective: System generated	5.0 %	63.3 % Loss 7.9 Litres	Nov	Dec	Jan
			Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	25.7 % Loss 1 Hours	Nov	Dec	Jan
			P-mode usage for EXC (% of working hours) Interim objective: System generated	1.0 %	2.1 % Loss Litres	Nov	Dec	Jan
			Total fuel l/h (including idle) Interim objective: System generated	13.7 l/h	14.9 l/h Loss 3.6 Litres	Nov	Dec	Jan
			Total machine hours Interim objective: System generated	12.2 Hours	3.0 Hours Loss 9.1 Hours	Nov	Dec	Jan
			Working fuel l/h (excluding idle) Interim objective: System generated	32.7 l/h	34.4 l/h Loss 1.3 Litres	Nov	Dec	Jan
AFS21-0056 (C480E310531), Other Building	139 Litres	13	Excessive idle (% of total machine hours) Interim objective: System generated	10.0 %	42.0 % Loss 4.1 Hours (29.5 Litres)	Nov	Dec	Jan
			H-mode usage for EXC (% of working hours) Interim objective: System generated	5.0 %	53.1 % Loss - 7.6 Litres	Nov	Dec	Jan
			Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	17.6 % Loss 5.4 Hours	Nov	Dec	Jan
			P-mode usage for EXC (% of working hours) Interim objective: System generated	1.0 %	7.4 % Loss .5 Litres	Nov	Dec	Jan
			Total fuel l/h (including idle) Interim objective: System generated	10.4 l/h	10.9 l/h Loss 7.5 Litres	Nov	Dec	Jan
			Total machine hours Interim objective: System generated	22.0 Hours	12.7 Hours Loss 9.3 Hours	Nov	Dec	Jan
			Working fuel l/h (excluding idle) Interim objective: System generated	22.9 l/h	27.1 l/h Loss 9.3 Litres	Nov	Dec	Jan
AFS 12-7336 (A40G340186), Other Building	990 Litres	108	Excessive idle (% of total machine hours) Interim objective: System generated	10.0 %	11.6 % Loss 1.7 Hours (6.5 Litres)	Nov	Dec	Jan
			Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	29.3 % Loss 33.1 Hours	Nov	Dec	Jan
			Minimum distance Interim objective: System generated	519.7 Km	229.8 km Loss 289.9 Km	Nov	Dec	Jan
			Total machine hours Interim objective: System generated	126.9 Hours	107.9 Hours Loss 19.1 Hours	Nov	Dec	Jan
AFS 12-7337 (A40G340190), Other Building	862 Litres	90	Excessive idle (% of total machine hours) Interim objective: System generated	10.0 %	21.8 % Loss 10.6 Hours (42.1 Litres)	Nov	Dec	Jan
			Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	35.5 % Loss 22.1 Hours	Nov	Dec	Jan
			Minimum distance Interim objective: System generated	606.4 Km	272.9 km Loss 333.6 Km	Nov	Dec	Jan
			Total machine hours Interim objective: System generated	172.3 Hours	90.1 Hours Loss 82.3 Hours	Nov	Dec	Jan

	Total		Objectives not fulfilled					
	Consumption	Hours	Objectives		Result			
AFS 12-7338 (A40G340241), Other Building	67 Litres	12	Excessive idle (% of total machine hours) Interim objective: System generated	10.0 %	63.4 % Loss 6.5 Hours (25.9 Litres)	Nov	Dec	Jan
			Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	6.7 % Loss 6.5 Hours	Nov	Dec	Jan
			Minimum distance Interim objective: System generated	719.2 Km	6.7 km Loss 712.6 Km	Nov	Dec	Jan
			Total machine hours Interim objective: System generated	151.6 Hours	12.3 Hours Loss 139.3 Hours	Nov	Dec	Jan
AFS 12-7339 (A40G340247), Other Building	373 Litres	51	Excessive idle (% of total machine hours) Interim objective: System generated	10.0 %	31.9 % Loss 11.3 Hours (38.1 Litres)	Nov	Dec	Jan
			Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	20.1 % Loss 20.5 Hours	Nov	Dec	Jan
			Minimum distance Interim objective: System generated	1,265.3 Km	68.0 km Loss 1 197.3 Km	Nov	Dec	Jan
			Total machine hours Interim objective: System generated	157.4 Hours	51.4 Hours Loss 106 Hours	Nov	Dec	Jan
AFS 22-0063 (L180H003495), Other Building	1 389 Litres	134	Excessive idle (% of total machine hours) Interim objective: System generated	10.0 %	22.2 % Loss 16.4 Hours (103.2 Litres)	Nov	Dec	Jan
			Machine utilization (% of total machine hours) Interim objective: System generated	60.0 %	38.1 % Loss 29.4 Hours	Nov	Dec	Jan
			Minimum distance Interim objective: System generated	674.5 Km	206.4 km Loss 468.1 Km	Nov	Dec	Jan
			Total machine hours Interim objective: System generated	172.3 Hours	134.3 Hours Loss 38 Hours	Nov	Dec	Jan

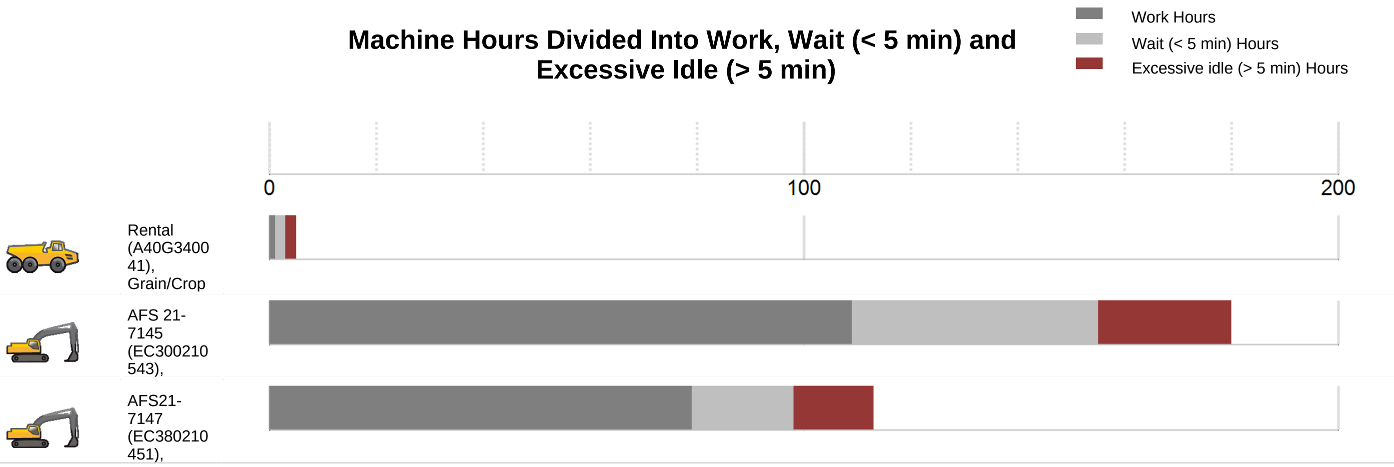
6. Machine Comparison - Machine Hours

The table compares total machine hours for all machines working in the same application.

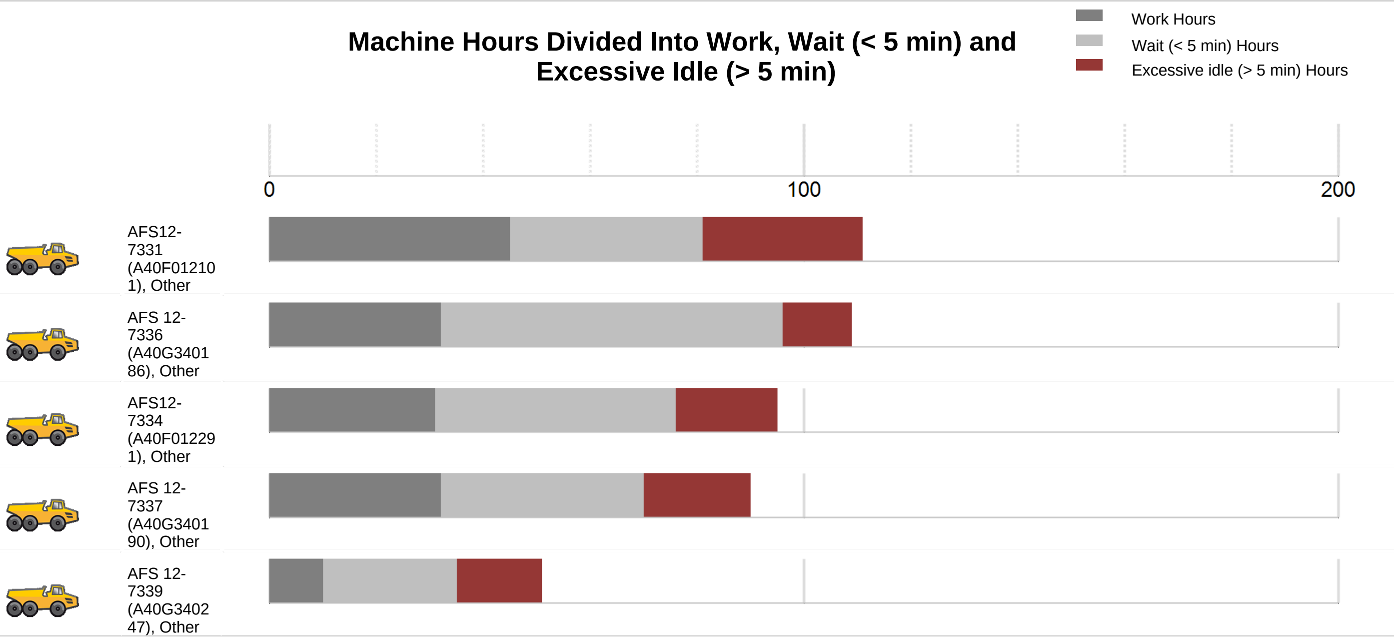
General Road Construction



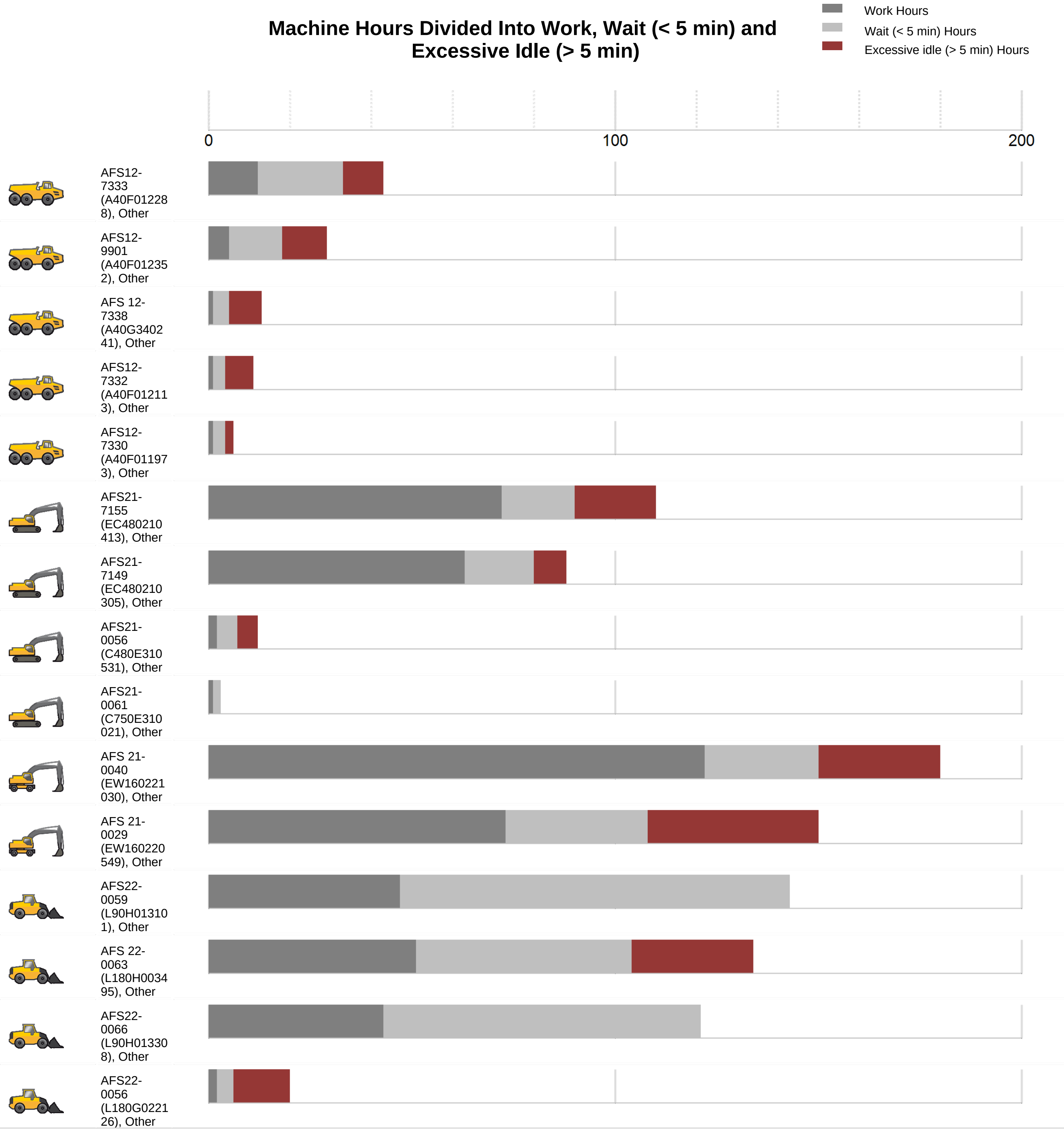
Grain/Crop Handling/Silage making



Other Building



Other Building

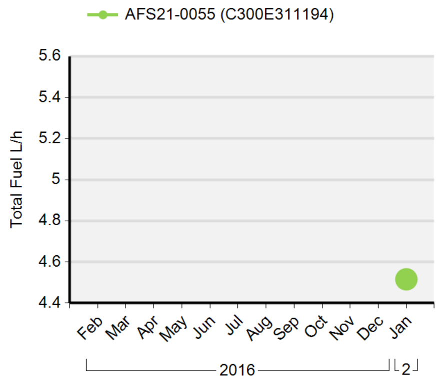


5. Machine Trends, by Application, by Machine Model

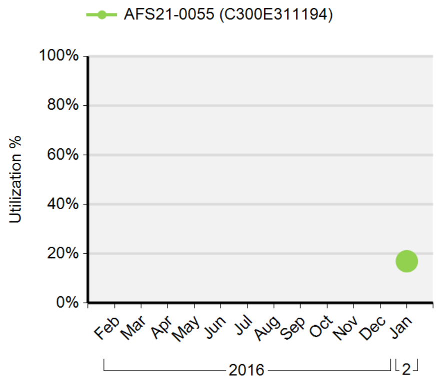
The trend graphs below present data for machines of the same generic model working with the same application.

General Road Construction - EC300

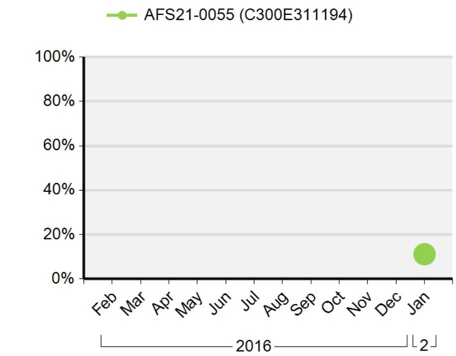
Total Fuel L/h (Including Idle)



Utilization (% of Machine Hours)

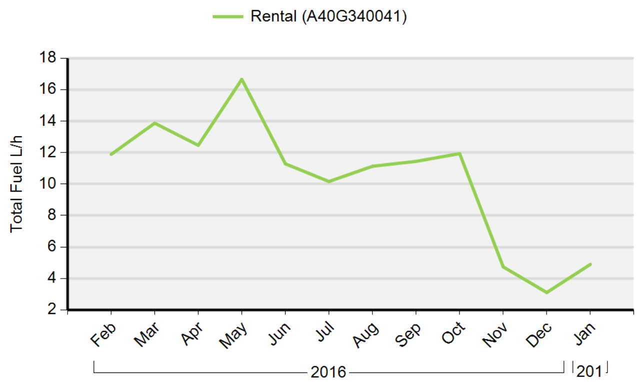


High Work Modes (Sum of H- and P-modes %)

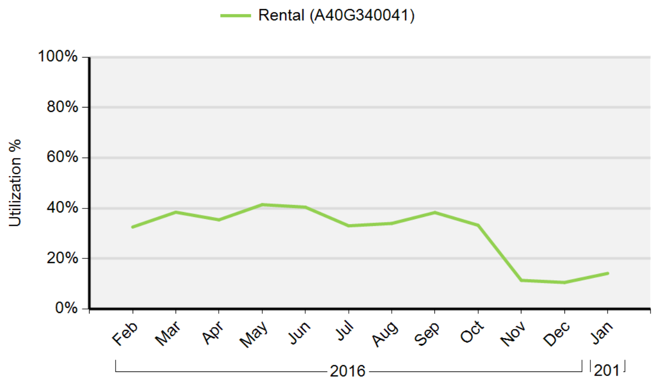


Grain/Crop Handling/Silage making - A40

Total Fuel L/h (Including Idle)

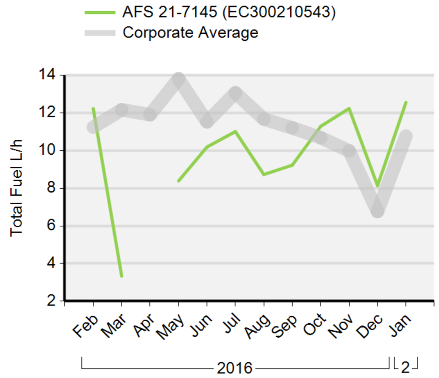


Utilization (% of Machine Hours)

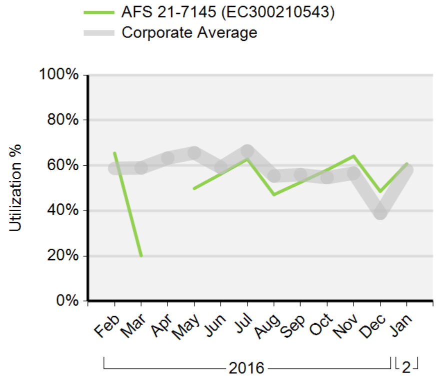


Grain/Crop Handling/Silage making - EC300

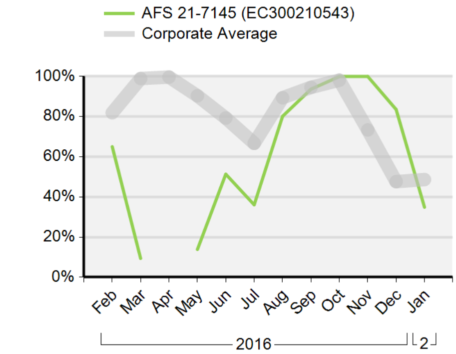
Total Fuel L/h (Including Idle)



Utilization (% of Machine Hours)

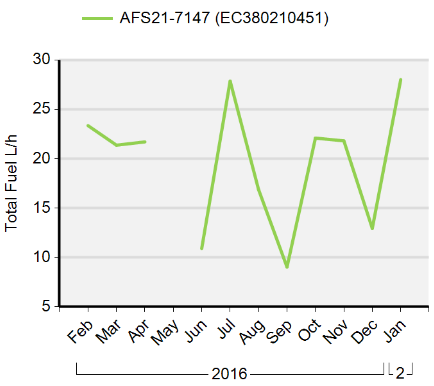


High Work Modes (Sum of H- and P-modes %)

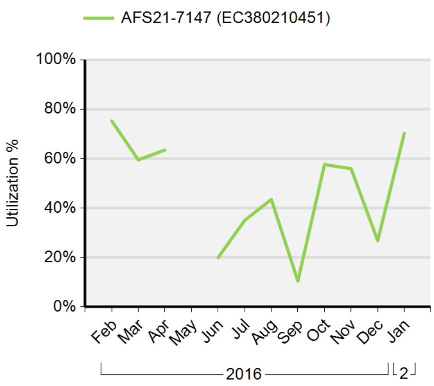


Grain/Crop Handling/Silage making - EC380

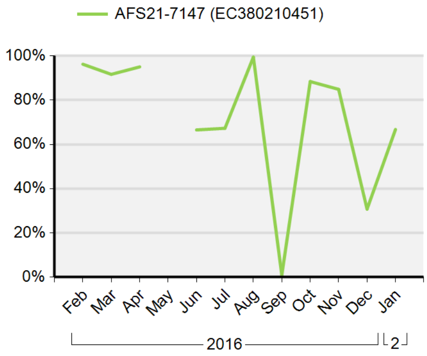
Total Fuel L/h (Including Idle)



Utilization (% of Machine Hours)

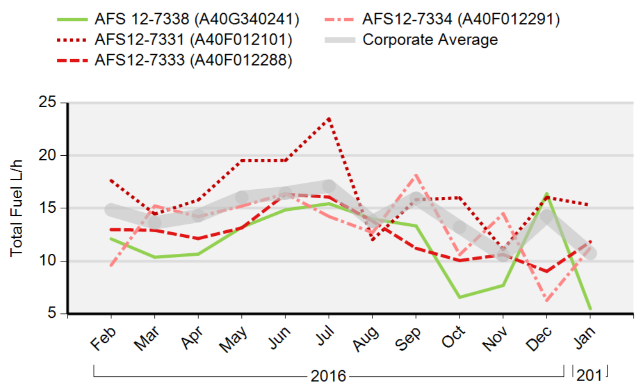


High Work Modes (Sum of H- and P-modes %)

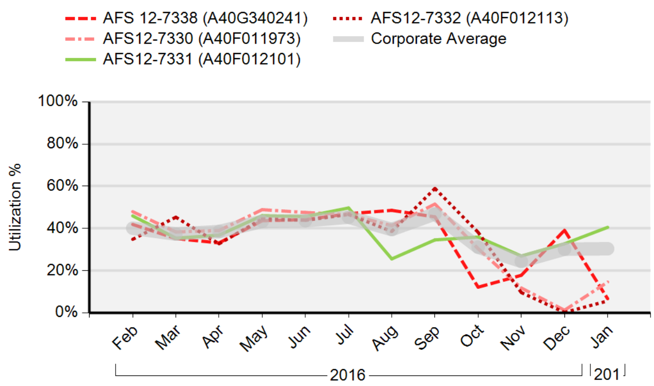


Other Building - A40 (6 Machines excluded)

Total Fuel L/h (Including Idle)

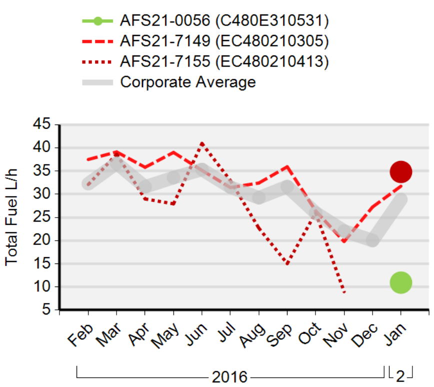


Utilization (% of Machine Hours)

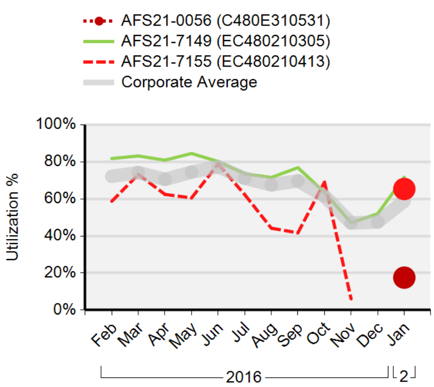


Other Building - EC480

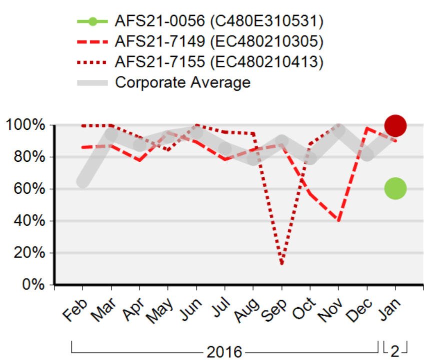
Total Fuel L/h (Including Idle)



Utilization (% of Machine Hours)

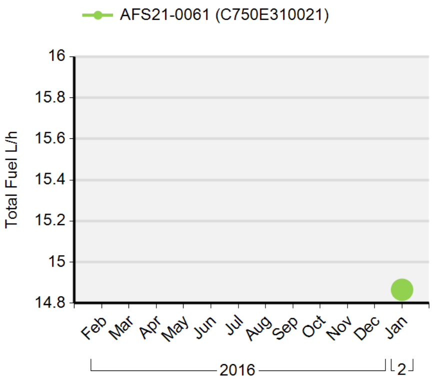


High Work Modes (Sum of H- and P-modes %)

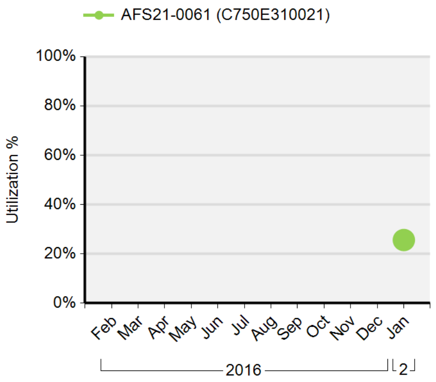


Other Building - EC750

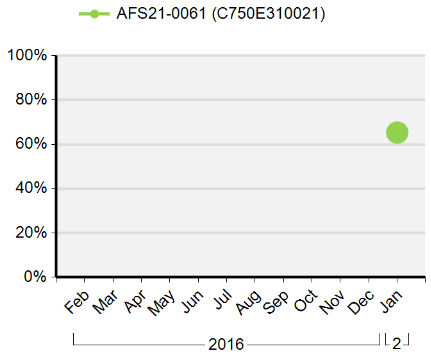
Total Fuel L/h (Including Idle)



Utilization (% of Machine Hours)

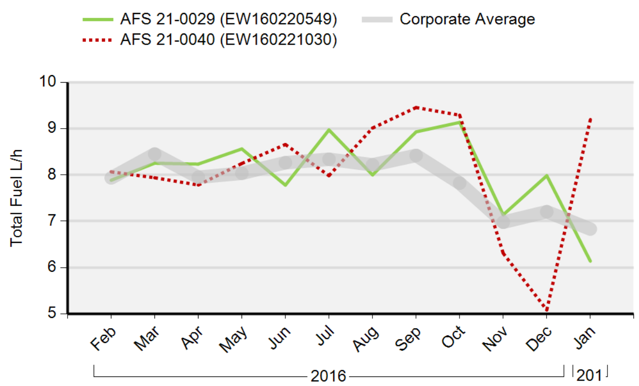


High Work Modes (Sum of H- and P-modes %)

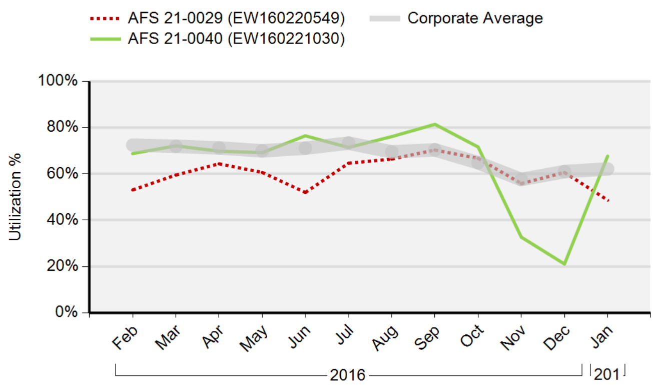


Other Building - EW160

Total Fuel L/h (Including Idle)

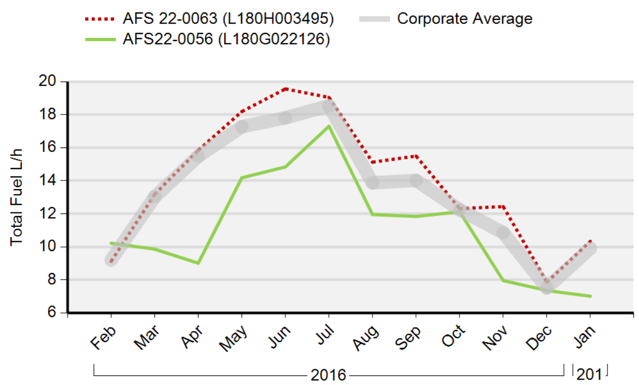


Utilization (% of Machine Hours)

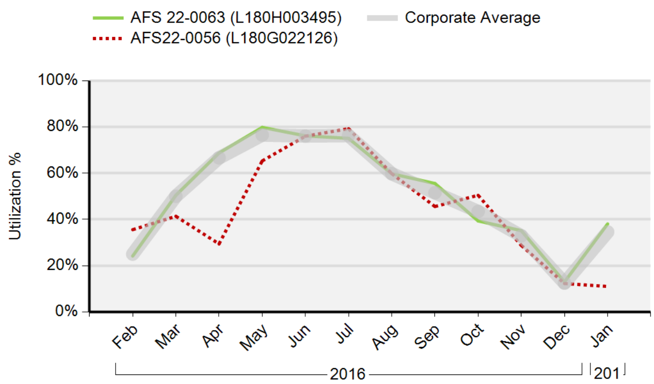


Other Building - L180

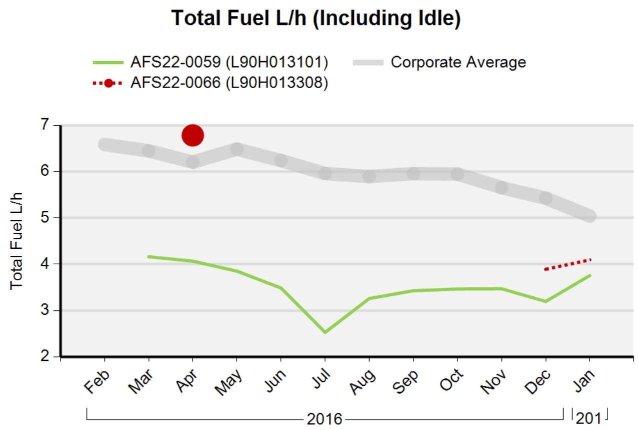
Total Fuel L/h (Including Idle)

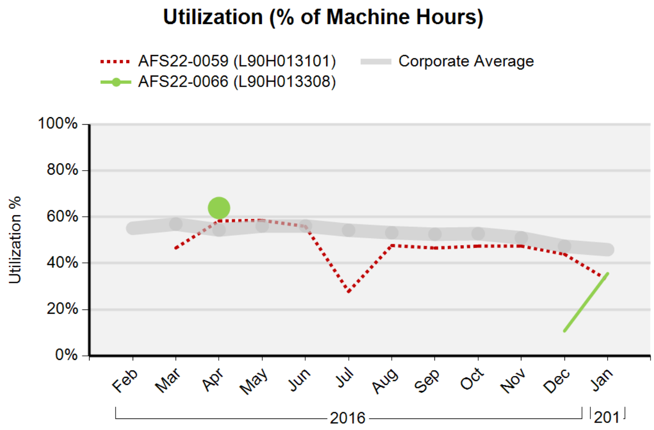


Utilization (% of Machine Hours)



Other Building - L90

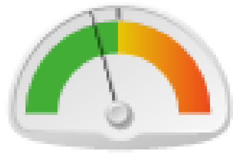


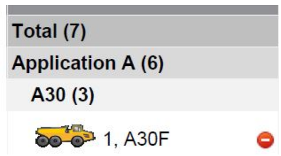


7. Help

Information concerning each section is presented below.

<table>
<tr><th>Section</th><th>Purpose</th><th>Example image</th></tr>
<tr><td>Dashboard</td><td>To see how you have performed compared to the objectives. If the needle is pointing up in a vertical line, you have exactly reached your objective. The aim is to stay in the green area.

Example to right: The performance is better compared to the objective.</td><td></td></tr>
<tr><td>Summary by Application</td><td>This time the grouping is made by machine application. Similar machines (based on model) that are working with the same job task/application are grouped together to best compare 'like for like' performance across the company.

Example to right: Seven machines are presented in the list, of which six of them are working with the job task "Application A" and three of them are of model A30.</td><td>
</td></tr>
<tr><td>Focus List</td><td>Up to eight different objectives can be defined on the machines with the help of the dealer, depending on the customer's situation. The system will initially state interim objectives for machines that are missing customer defined objectives. These are named "Interim objective: System generated" and that text will appear below the objective when applicable. The system states these interim objectives for each machine based upon historical average performance, and they could be used as guidelines when starting to define the objectives.

Two levels for each objective are stated, taking "Excessive idle (> 5 min)" as an example.

<table>
<tr><th></th><th></th><th>Objective:</th><th></th><th></th><th>Critical alert:</th><th></th></tr>
<tr><td>(green)</td><td></td><td>The machine is allowed to stand still max. 10% of total hours</td><td>(yellow)</td><td></td><td>It's critical if the machine is standing still more than 15% of total hours.</td><td>(red)</td></tr>
</table>

The following objective can be used:

<table>
<tr><td>1</td><td>Overall l/h (idle included)</td><td>Measure how fuel efficient the machine has been in it's overall work cycle (total fuel including idle divided with hours)</td></tr>
<tr><td>2</td><td>L/h during work (idle excluded)</td><td>Measure how fuel efficient the machine has been operated while working (note, idle consumption not included, not the same as litres/hour above).</td></tr>
<tr><td>3</td><td>Utilization %</td><td>The % of time the machine has been in working mode compared to total machine hours.</td></tr>
<tr><td>4</td><td>Excessive idle (> 5 min)</td><td>The % of total hours. This measurement can be used to decrease the time spent standing still more than five minutes (excessive idle).</td></tr>
<tr><td>5</td><td>Machine hours</td><td>The total number of hours per week (Work hours + Waiting hours (machine standing still less than 5 min) + Excessive idle hours (machine standing still more than 5 min).</td></tr>
<tr><td>6</td><td>H-mode usage for crawler excavators (% of working hours)</td><td>Measure the % of the total working hours the machine has operated in H-mode. Some job tasks/situations require H-mode usage, but sometimes unnecessary use of this mode can cause excessive fuel consumption.</td></tr>
<tr><td>7</td><td>P-mode usage for crawler excavators (% of working hours)</td><td>Measure the % of the total working hours the machine has operated in P-mode. Some job tasks/situations require P-mode usage, but sometimes unnecessary use of this mode can cause excessive fuel consumption.</td></tr>
</table></td><td>
</td></tr>
</table>

8	Distance	Number of machine kilometres per week.

The machines that didn’t achieve their monthly objectives are presented in the focus list (both the ones with ‘yellow’ status and the ones with ‘red’ status).

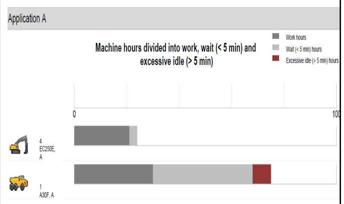
Note: An objective is not stated for Wait (machine standing still less than 5 min).

Example to right: Two machines working with “Application A” failed to reach the desired level of performance for four objectives.

Machine Comparison - Machine Hours

Visual comparison of hours (divided in work, wait, and excessive idle) between machines working in same application.

Example to right: Machine number two has spent more time standing still more than 5 minutes (excessive idle), compared to machine number one.

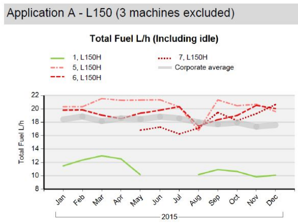


Machine Trends, by Application, by Machine Model

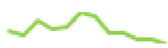
The purpose is to identify the best and worst machines using two objectives: Total fuel l/h, and utilization (% of machine hours). Taking total fuel l/h as an example: The machine that consumed least l/h in the current month is presented with a green line to highlight achievements. The three machines that consumed most l/h are presented with red lines.

The machines are grouped by model and by application. All machines are presented if there are less than four machines of the same model that work in the same application. Not all machines are presented to avoid overloading the graph. If there are more than four machines, all will not be presented in the line diagram. However, these machines that are kept out are still taken in to consideration in the average figure.

Example to right: There are seven machines altogether of model L150 working with the application “Application A”. The graph contains four of them and three are excluded.



Total fuel l/h used as example below:

Machine	Total Fuel L/h	Presented in graph?	
1	10.0	Presented as the machine with lowest l/h	
2	17.1	No (but value is included in average line)	
3	18.3	No (but value is included in average line)	
4	19.5	No (but value is included in average line)	
5	19.8	Presented as the machine with third highest l/h	
6	20.0	Presented as the machine with second highest l/h	
7	20.3	Presented as the machine with highest l/h	
Average of all seven machines above::	17.9	Contains average for machines of same model working in the same application	

Information concerning the various definitions is presented below.

Total					
Work				**Idle**	
Machine utilized				Machine partly utilized	
Excavator	*Wheel loader*	*Articulated hauler*		*Wait*	*Excessive idle*
Attachment in use - and/or travel operation	Machine rpm > 850 and/or speed > 0,5 km/h	Transmission not in neutral		Machine standing still less than 5 minutes with engine at idle.	Machine standing still more than 5 minutes with engine at idle.

Disclaimers from CareTrack and MATRIS are valid for Efficient Operation Services. Volvo CE realizes that the complexity in which we are working can create unforeseen problems and that inaccuracy of data is possible. Therefore we kindly ask you to report any errors as soon as possible.

TRANSFERRING
VOLVO

Machine Operating Information Report

NASTA AS

Report No.	DRP-F2610052000-0000848699-0019

Customer

NASTA UTLEIE AS

Machines under ConSite Contract

Model Code	Model Name	S/N	PIN/VIN
DDN50	ZX300LC-6	060072	HCMDDN50C00060072
Machine ID			

Date of Issue	Reporting Period
26/02/2018	01/01/2018 to 31/01/2018

Contents and Summaries

Operating Hours and Conditions

- Operating Conditions
- ECO Operation Report
- Operating Hours (Details)
- Analysis of Operating Condition

Summary	
No. of Operating Days	17 Days
Engine Operating Hours	157.9 hr(s)
Fuel Consumption	2,456 l
Ratio of Eco Mode Usage	0 %
ECO Index (Non-Operation Ratio)	A B C $\boxed{D}$
ECO Index (Swing Operation Ratio)	A B $\boxed{C}$ D

Attachment Operation Hours

- Total Operation Hours for this month

Summary	
Operation hours for this month	40.0 hr(s)

Transition of Highest Coolant Temperatures

- Transition of Daily Highest Temperatures

Summary	
Monthly averaged highest temperature	Mid

Transition of Highest Hydraulic Oil Temperatures

- Transition of Daily Highest Temperatures

Summary	
Monthly averaged highest temperature	Low

Distribution of Temperatures

- Coolant Temperature Distribution Chart
- Hydraulic Oil Temperature Distribution Chart

Summary	
Coolant	The machine operated mostly in the "Low" temperature range.
Hydraulic Oil	The machine operated mostly in the "Low" temperature range.

Tendency of Pump Pressure in the latest 200hrs

- Pump Pressure
- Pump Pressure (Digging)
- Pump Pressure (Traveling)
- Pump Pressure (Swing)

Summary	
Pump Pressure	The machine operated mostly in the "Low" pump pressure range.
Pump Pressure (Digging)	The machine operated mostly in the "Mid" pump pressure range.
Pump Pressure (Traveling)	The machine operated mostly in the "Mid" pump pressure range.
Pump Pressure (Swing)	The machine operated mostly in the "High" pump pressure range.

Daily Operating Report

- Daily Operating Report (Details)

Summary	
Actual Operating Hours	78.2 hr(s)
Non-Operation Hours	79.8 hr(s)

Alarm Issuance History

- Table of alarms issued

Summary	
Number of ConSite alarms during the reporting month	0 Times

Note: This report is based on data that has been registered on Global e-Service. It may not reflect the latest condition of the machine.

Operating Hours and Conditions		Report No.	DRP-F2610052000-0000848699-0019
		Machine ID	
Model Name	ZX300LC-6	Reporting Period	01/01/2018 to 31/01/2018
S/N	060072	Date of Issue	26/02/2018

Operating Conditions

Latest Hour Meter Reading	1,800 hr(s)	Time since Delivery	0Year(s) 11Month(s)
No. of Operating Days	17 Days	Engine Operating Hours	157.9 hr(s)

Operating Conditions Calendar

Sun.	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
	1	2 14.2 213	3 11.9 208	4 10.6 168	5	6
7	8 12.6 211	9 13.7 210	10 15.0 241	11 5.1 57	12	13
14	15 11.1 194	16 11.0 201	17 12.2 194	18 2.6 41	19	20
21	22 10.3 152	23 7.1 89	24 4.5 63	25	26	27
28	29 6.8 102	30 2.4 28	31 6.8 88			

Color Legend

15.0 / 225	Daily operating hours are 6.1 hrs or more.
5.0 / 75	Daily operating hours are 6.0 hrs or less.
2.0 / 30	Daily operating hours are 4.0 hrs or less.
	No Operating

Item Legend

1	Date
5.0	Operating Hours[hr(s)]
75	Fuel Consumption[l]

Power Mode Ratio

PWR Mode	100 %	ECO Mode	0 %

* Fuel consumption can be improved by using ECO mode.

Fuel Efficiency & CO2

Fuel Consumption	2,456 l	Over Preceding Month	+1,638 l

* The fuel consumption amount shown above was theoretically calculated and is slightly different from the actually consumed amount. It is either calculated from theoretical injection amounts or extrapolated from hydraulic pump loads.

Fuel Efficiency	15.5 l/hr	Over Preceding Month	-1.0 l/hr

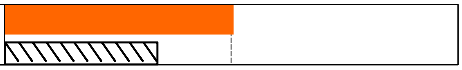
* Fuel efficiency is calculated based on fuel consumption / operating hours. Fuel Efficiency improves with less non-operation hours.

CO2 Emission Amount	6,335 kg	Over Preceding Month	+4,225 kg

* The CO2 emission amount was calculated based on the fuel consumption amount.

ECO Operation Report

Non-Operation Ratio	50 %(79.8 hr(s))



* The upper graph shows the value of the target machine.
  The lower graph shows the average value of the region & model class.

Index	A	B	C	D

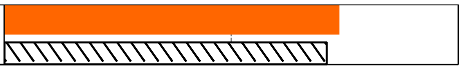
Efficient

Comment	Non-Operation ratio is very high. Fuel consumption can be reduced a lot by stopping the engine during waiting time or short rest. Also, there is a possibility that a mechanical or electrical problem might have contributed to the high non-operation hours.

* Approximately 2 l/hr of fuel is consumed during idling and 4 l/hr of fuel is consumed during auto idling.

A:Non-Operation ratio is 0 to 18%
B:Non-Operation ratio is 19 to 30%
C:Non-Operation ratio is 31 to 42%
D:Non-Operation ratio is 43 to 100%

Swing Operation Ratio	73 %(57.7 hr(s))



* The upper graph shows the value of the target machine.
  The lower graph shows the average value of the region & model class.

Index	A	B	C	D

Efficient

Comment	Swing operating time ratio is very high. In general, work efficiency can be improved by reducing swing ratio.

A:Swing Operation ratio is 0 to 61%
B:Swing Operation ratio is 62 to 69%
C:Swing Operation ratio is 70 to 77%
D:Swing Operation ratio is 78 to 100%

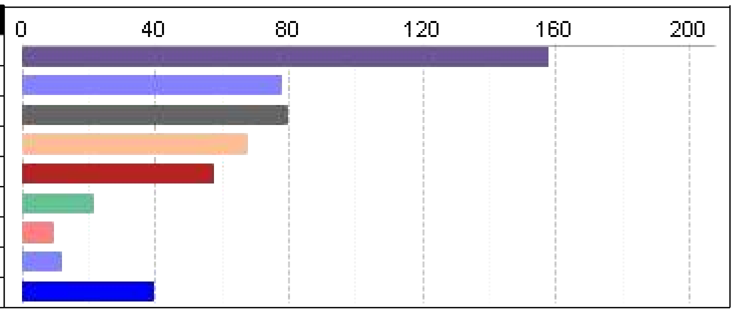
Note: This report is based on data that has been registered on Global e-Service. It may not reflect the latest condition of the machine.

Operating Hours and Conditions		Report No.	DRP-F2610052000-0000848699-0019
		Machine ID	
Model Name	ZX300LC-6	Reporting Period	01/01/2018 to 31/01/2018
S/N	060072	Date of Issue	26/02/2018

Operating Hours (Details)

Operating Hours of the Reporting Period

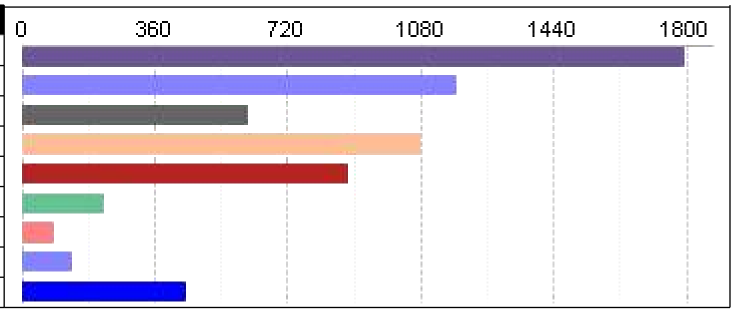
Item	Current Month
Engine Operating Hours	157.9 hr(s)
Actual Operating Hours	78.2 hr(s)
Non-Operation Hours	79.8 hr(s)
Front Operation Hours	68.1 hr(s)
Swing Operation Hours	57.7 hr(s)
Travel Operation Hours	21.7 hr(s)
Fast Speed Mode	9.7 hr(s)
Slow Speed Mode	12.0 hr(s)
Attachment Operation Hours	40.0 hr(s)



* Total hours of operation may exceed engine running time due to combined operation.

Cumulative Operating Hours

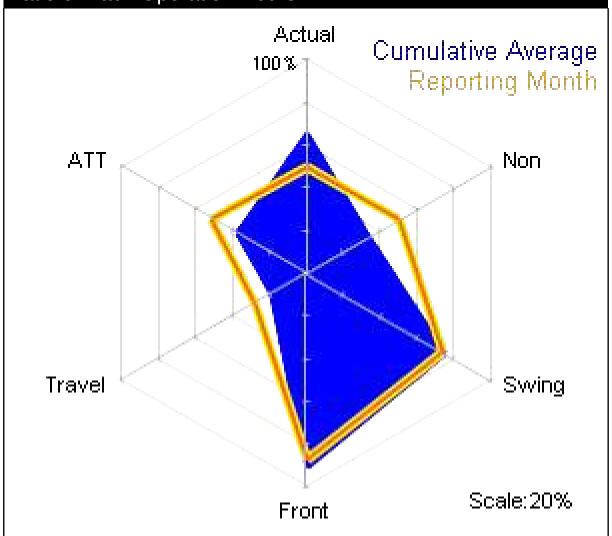
Item	Cumulative Total
Engine Operating Hours	1,796.4 hr(s)
Actual Operating Hours	1,180.6 hr(s)
Non-Operation Hours	615.8 hr(s)
Front Operation Hours	1,079.7 hr(s)
Swing Operation Hours	886.0 hr(s)
Travel Operation Hours	222.3 hr(s)
Fast Speed Mode	87.2 hr(s)
Slow Speed Mode	138.2 hr(s)
Attachment Operation Hours	447.5 hr(s)



* Total hours of operation may exceed engine running time due to combined operation.

Analysis of Operating Condition

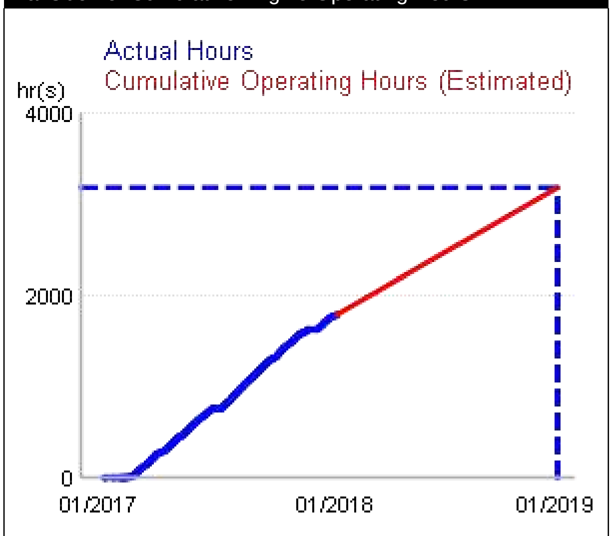
Ratio of Each Operation Hours



Comment	Non,ATT Operation Hours in this month is higher than Cumulative operating average. Actual Operation Hours in this month is lower than Cumulative operating average.

* Actual operating time ratio and non-operating time ratio are respective time ratios to the engine operating time. Other time ratios are ratios to the actual operating time.

Transition of Cumulative Engine Operating Hours



Estimated Engine Operating Hours (After one year)	3,191 hr(s)

* The estimated hours are calculated based on the cumulative engine operating hours up to the reporting month. Actual operating hours will be greatly different from the estimated hours if the machine's operating site or condition changes.

Expected Milestone Dates			
2,000 hr(s)	2,250 hr(s)	2,500 hr(s)	2,750 hr(s)
25/03/2018	30/05/2018	04/08/2018	09/10/2018

Note: This report is based on data that has been registered on Global e-Service. It may not reflect the latest condition of the machine.

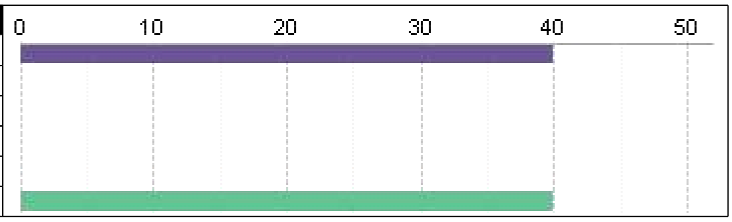
Attachment Operation Hours		Report No.	DRP-F2610052000-0000848699-0019
		Machine ID	
Model Name	ZX300LC-6	Reporting Period	01/01/2018 to 31/01/2018
S/N	060072	Date of Issue	26/02/2018

Total Operation Hours for this month

The table shows the operation hours in each attachment mode set by the monitors.

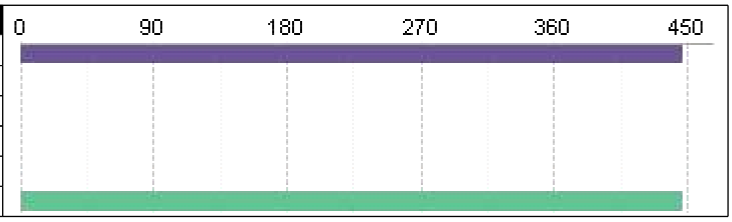
Operating Hours of the Reporting Period

Item	Current Month
Attachment Operation Hours	40.0 hr(s)
Breaker Operation	0.0 hr(s)
Pulverize Operation	0.0 hr(s)
Crusher Operation	0.0 hr(s)
Vibration Hammer Operation	0.0 hr(s)
Other Attachment Operation	40.0 hr(s)



Cumulative Operating Hours

Item	Cumulative Total
Attachment Operation Hours	447.5 hr(s)
Breaker Operation	0.0 hr(s)
Pulverize Operation	0.0 hr(s)
Crusher Operation	0.0 hr(s)
Vibration Hammer Operation	0.0 hr(s)
Other Attachment Operation	447.4 hr(s)



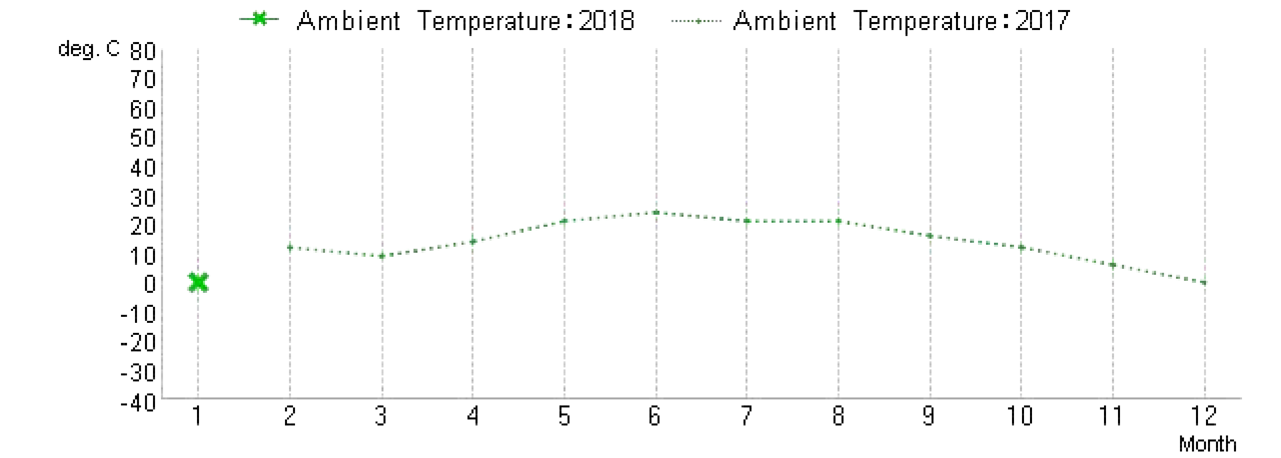
Transition of Highest Coolant Temperatures		Report No.	DRP-F2610052000-0000848699-0019
		Machine ID	
Model Name	ZX300LC-6	Reporting Period	01/01/2018 to 31/01/2018
S/N	060072	Date of Issue	26/02/2018

Transition of Daily Highest Temperatures

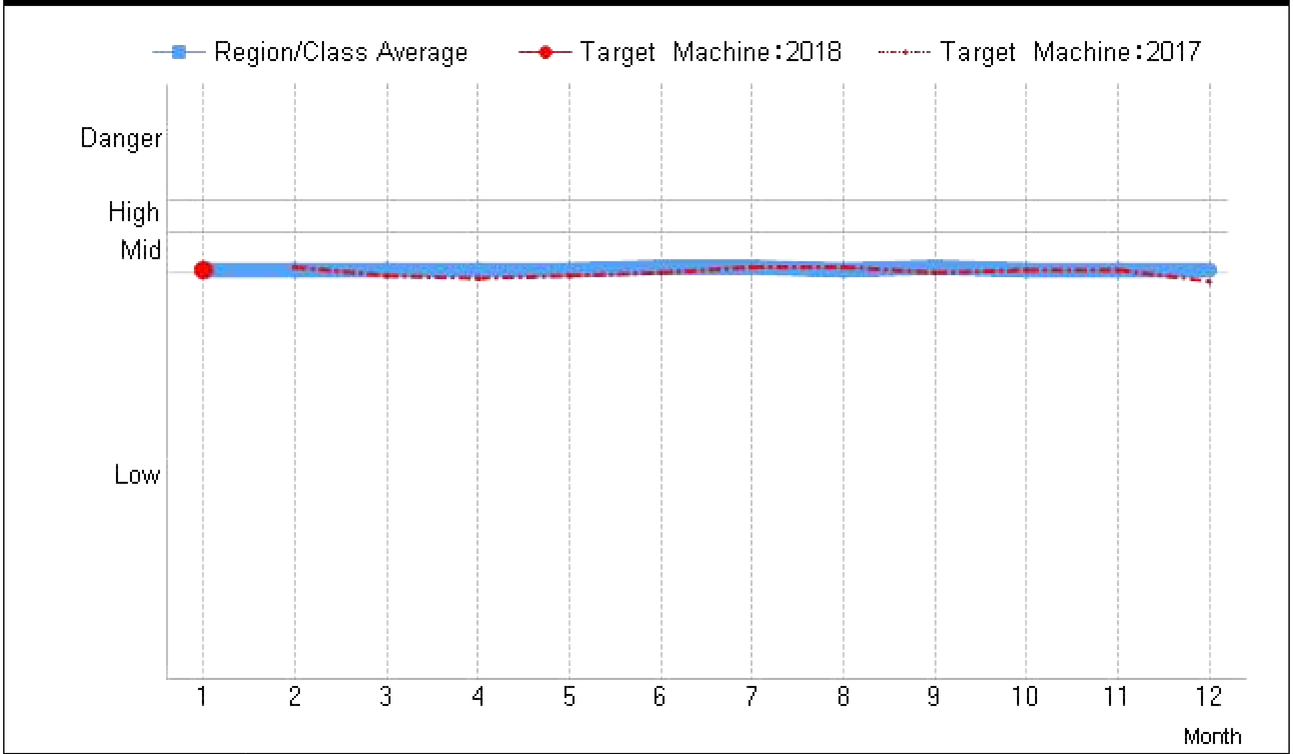
The following graph indicates transition of monthly averaged daily highest temperatures.

Reporting Period	01/01/2017 to 31/01/2018

Transition of average ambient temperature



Transition of Daily Highest Temperatures



Comment	The coolant temperature of the reporting month was in the "Mid" temperature range.

* Danger: Excessively high temperature range (overheating).
* Low, Mid, and High: Normal temperature range.

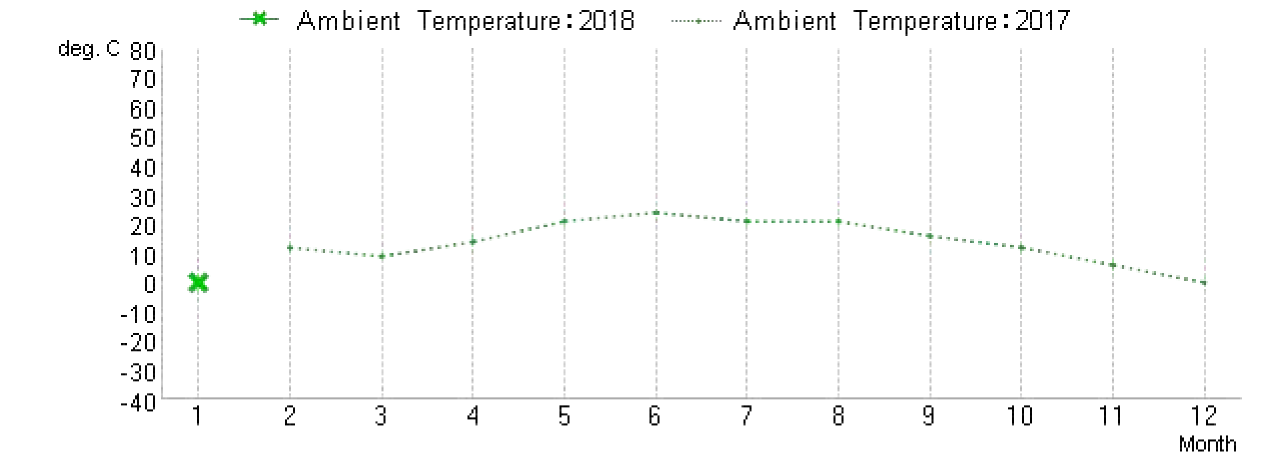
Transition of Highest Hydraulic Oil Temperatures		Report No.	DRP-F2610052000-0000848699-0019
		Machine ID	
Model Name	ZX300LC-6	Reporting Period	01/01/2018 to 31/01/2018
S/N	060072	Date of Issue	26/02/2018

Transition of Daily Highest Temperatures

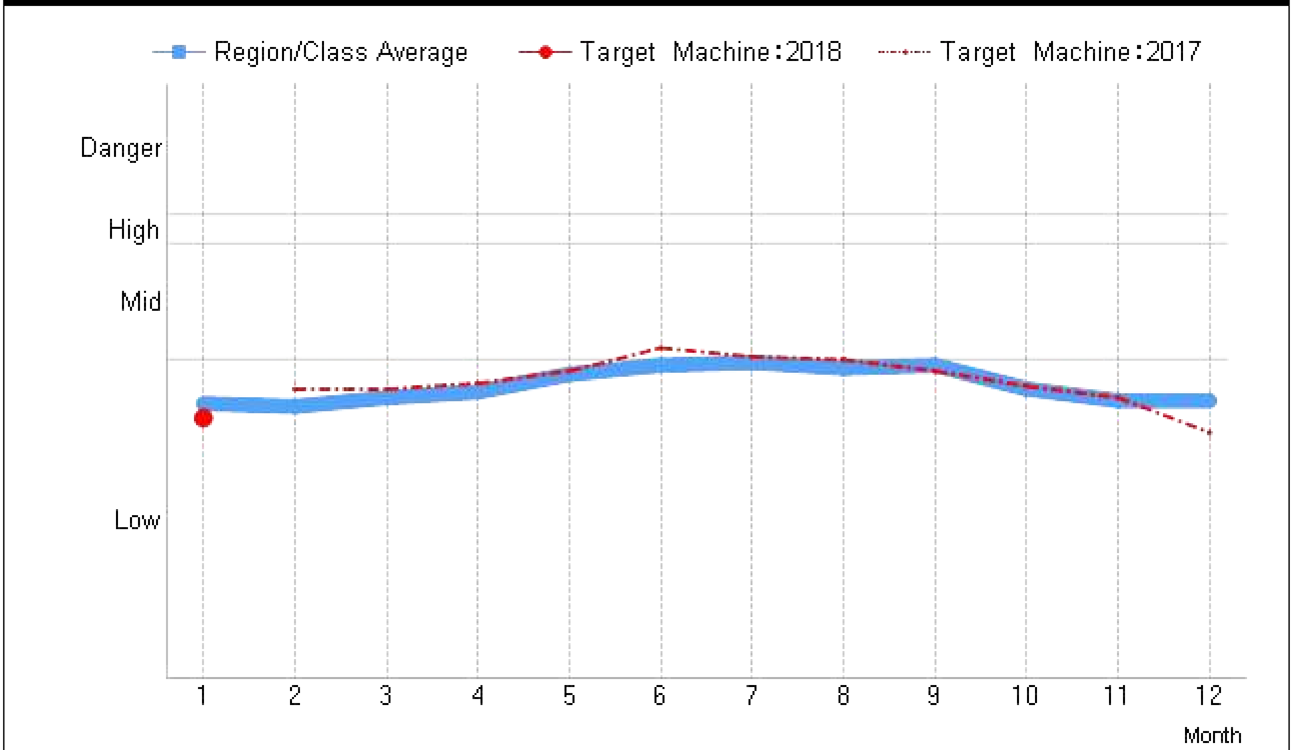
The following graph indicates transition of monthly averaged daily highest temperatures.

Reporting Period	01/01/2017 to 31/01/2018

Transition of average ambient temperature



Transition of Daily Highest Temperatures



Comment	The hydraulic oil temperature of the reporting month was in the "Low" temperature range.

* Danger: Excessively high temperature range (overheating).

* Low, Mid, and High: Normal temperature range.

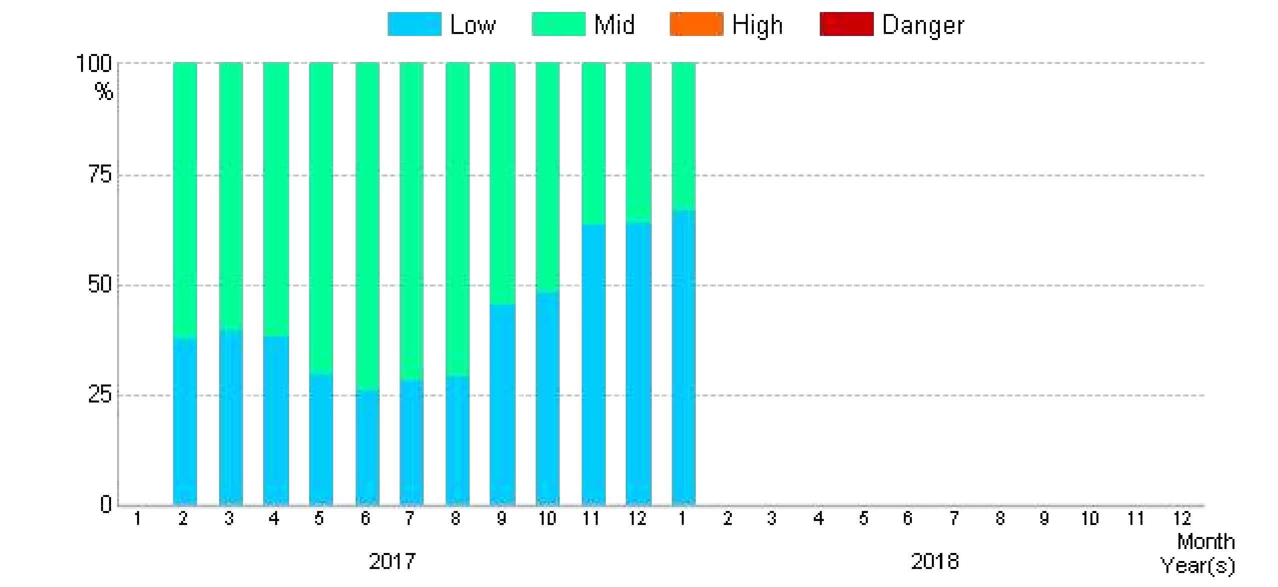
Distribution of Temperatures		Report No.	DRP-F2610052000-0000848699-0019
		Machine ID	
Model Name	ZX300LC-6	Reporting Period	01/01/2018 to 31/01/2018
S/N	060072	Date of Issue	26/02/2018

Distribution of Temperatures

The graph shows the monthly distribution of temperatures with a summary of daily temperature.

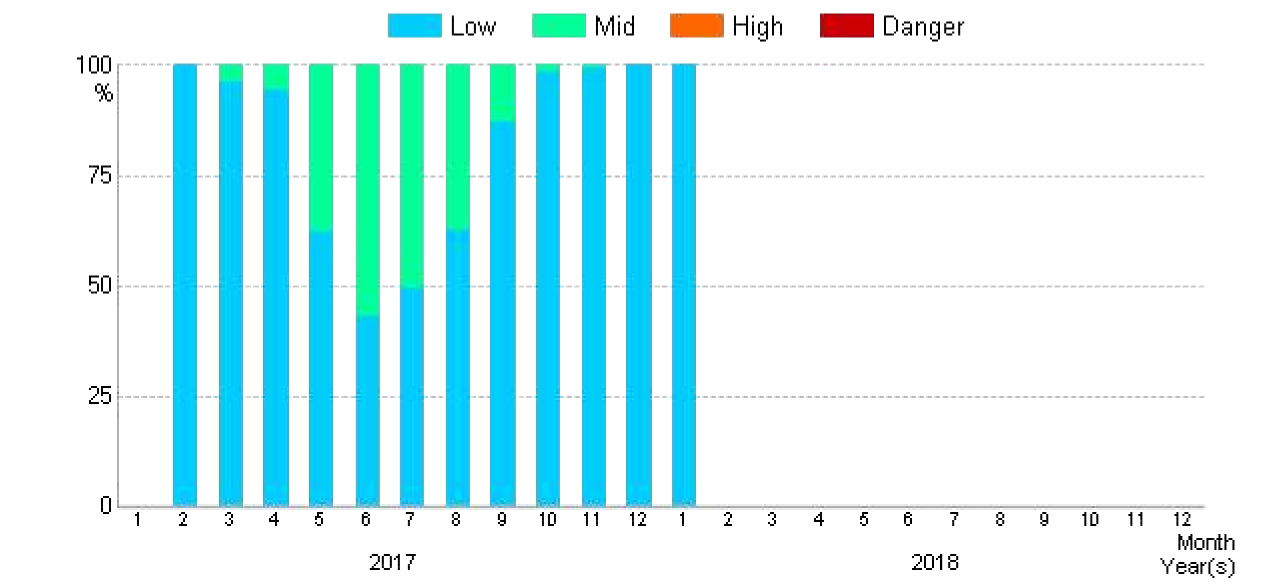
Reporting Period	01/01/2017 to 31/01/2018

Coolant Temperature Distribution Chart



Comment	The coolant temperature of the reporting month was in the "Low" temperature range.

Hydraulic Oil Temperature Distribution Chart



Comment	The hydraulic oil temperature of the reporting month was in the "Low" temperature range.

* Danger: Excessively high temperature range (overheating).
* Low, Mid, and High: Normal temperature range.

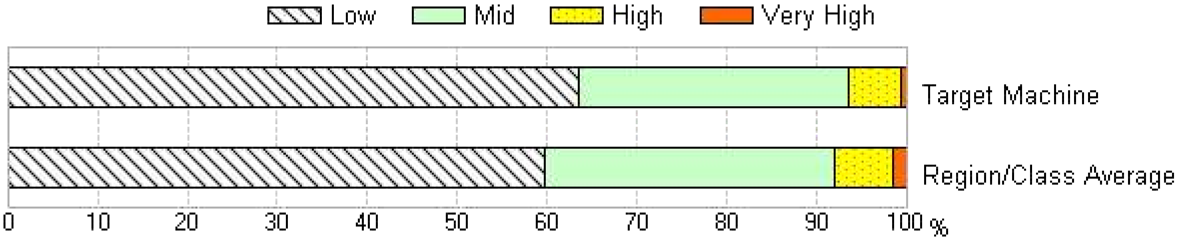
Tendency of Pump Pressure in the latest 200hrs		Report No.	DRP-F2610052000-0000848699-0019
		Machine ID	
Model Name	ZX300LC-6	Reporting Period	01/01/2018 to 31/01/2018
S/N	060072	Date of Issue	26/02/2018

Tendency of Pump Pressure in the latest 200hrs

The graphs below show the range of pressure in the reporting period.

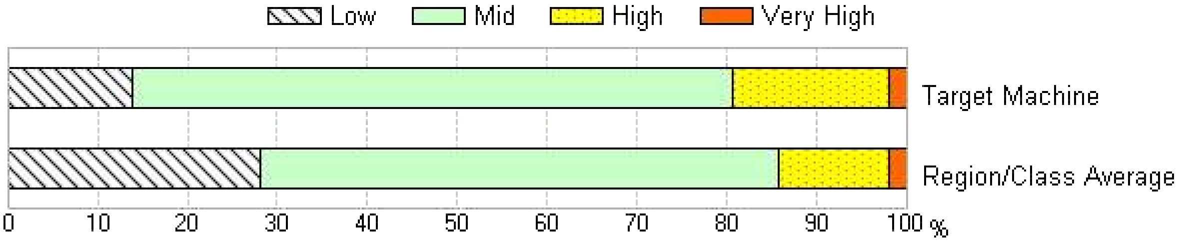
Reporting Period	1,600 hr(s) to 1,800 hr(s)

Pump Pressure



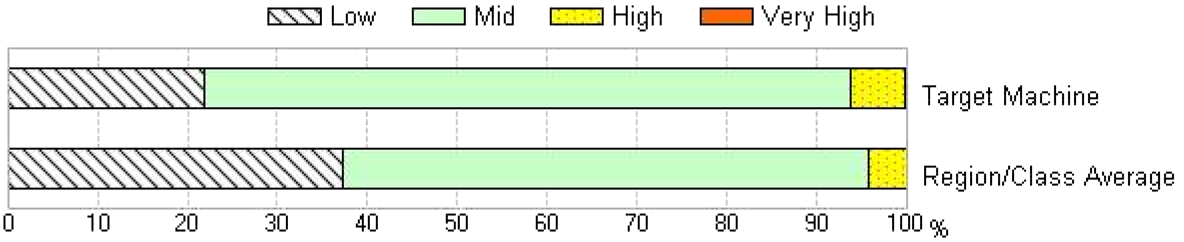
Comment	The machine operated mostly in the "Low" pump pressure range. The lower bar chart indicates the regional & class average.

Pump Pressure (Digging)



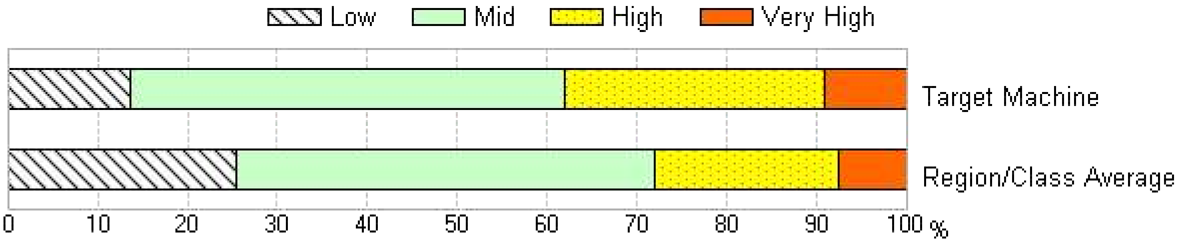
Comment	The machine operated mostly in the "Mid" pump pressure range. The lower bar chart indicates the regional & class average.

Pump Pressure (Traveling)



Comment	The machine operated mostly in the "Mid" pump pressure range. The lower bar chart indicates the regional & class average.

Pump Pressure (Swing)



Comment	The machine operated mostly in the "High" pump pressure range. The lower bar chart indicates the regional & class average.

Note: This report is based on data that has been registered on Global e-Service. It may not reflect the latest condition of the machine.

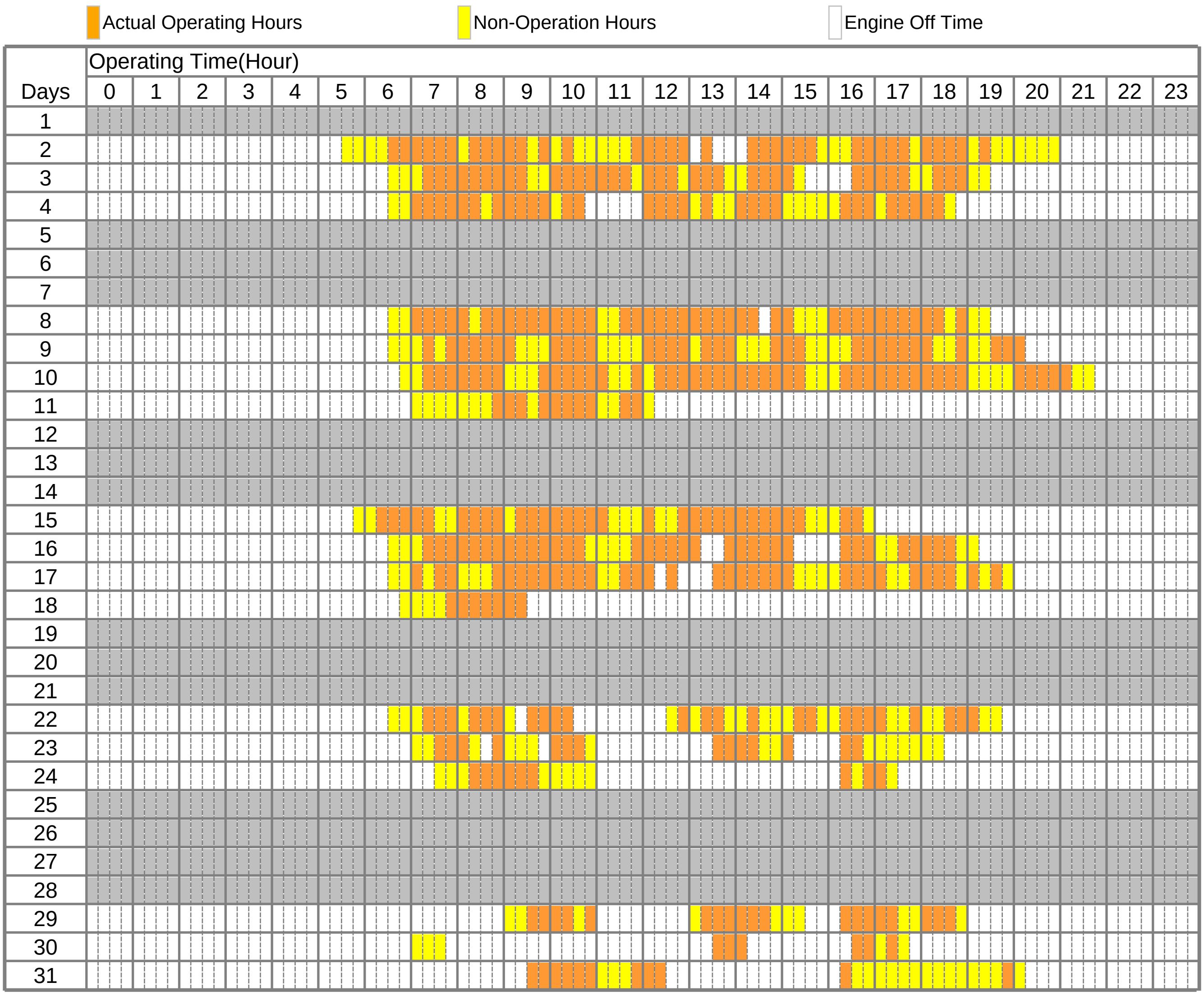
Daily Operating Report		Report No.	DRP-F2610052000-0000848699-0019
		Machine ID	
Model Name	ZX300LC-6	Reporting Period	01/01/2018 to 31/01/2018
S/N	060072	Date of Issue	26/02/2018

Daily Operating Report (Details)

Daily operating data during the reporting period is indicated below.

Operating Hours of the Reporting Period

Engine Operating Hours	157.9 hr(s)
Actual Operating Hours	78.2 hr(s)
Non-Operation Hours	79.8 hr(s)



* : No operating information available.

Note: This report is based on data that has been registered on Global e-Service. It may not reflect the latest condition of the machine.

Alarm Issuance History		Report No.	DRP-F2610052000-0000848699-0019
		Machine ID	
Model Name	ZX300LC-6	Reporting Period	01/01/2018 to 31/01/2018
S/N	060072	Date of Issue	26/02/2018

Table of alarms issued

ConSite alarms during the reporting period are shown in the reverse order of issuance up to as many as can be shown on one page.

Number of ConSite alarms during the reporting month	0 Times

Issuance date/Number of alarms	ConSite Fault Name	ConSite Fault Code

Note: This report is based on data that has been registered on Global e-Service. It may not reflect the latest condition of the machine.

Supplement: Explanation of Terminology		Report No.	DRP-F2610052000-0000848699-0019
		Machine ID	
Model Name	ZX300LC-6	Reporting Period	01/01/2018 to 31/01/2018
S/N	060072	Date of Issue	26/02/2018

Explanation of Terms Used In This Report

Item	Description
Engine Operating Hours	Total hours of Actual Operating Hours and Idling Time.
Engine Off Time	Time in which the engine is not running.
Front Operation Hours	Total front operation hours of the machine.
Swing Operation Hours	Total swing operation hours of the machine.
Travel Operation Hours	Total travel operation hours of the machine.
Non-Operation Hours	Total non-operation hours of the machine (Idling Time)
Actual Operating Hours	Hours which are gotten by subtracting Non-Operation Hours from engine operating hours
Pump Pressure	Pump pressure during digging, travel, and swing lever operation.
Pump Pressure (Digging)	Pump pressure during front lever operation
Pump Pressure (Traveling)	Pump pressure during travel lever operation
Pump Pressure (Swing)	Pump Pressure during swing lever operation
Ambient Temperature	Ambient temperatures recorded on the machine tend to be higher than the actual surrounding area temperatures since the sensor is located inside the engine cover.

CUSTOMER	Year	Month	ChassiId	Model
Ukjent	2017	jan.17	A35F010220	A35F
Ukjent	2017	jan.17	C250E320278	EC250E
Ukjent	2017	jan.17	C380E310078	EC380E
Ukjent	2017	jan.17	L110H010962	L110H
Ukjent	2017	jan.17	L120H015300	L120H
Ukjent	2017	feb.17	A40F011661	A40F
Ukjent	2017	feb.17	EW160122062	EW160C

Machine name	Region	Site
A35F010220	Landsdel X	Anleggsområde X
C250E320278	Landsdel X	Anleggsområde X
C380E310078	Landsdel X	Anleggsområde X
L110H010962	Landsdel X	Anleggsområde X
L120H015300	Landsdel X	Anleggsområde X
A40F011661	Landsdel X	Anleggsområde X
EW160C122062	Landsdel X	Anleggsområde X

Application	Total life-time hours	Machine Hours	Utilization %
Other Building	23041	3,8	8,9
Other Building	4961	1,7	38,5
Other Building	15200	3	51,1
Mixing Plants Asphalt/Concrete	29961	50,3	54,1
Mixing Plants Asphalt/Concrete	4924	17,6	42,9
Other Building	105483	90,4	38,9
Other Industrial Material Handling	149227	149,8	58,4

Idle (Wait < 5 min + Excessive Idle > 5 min) %	Wait (standing still < 5 min) %
91,1	54,6
61,5	61,5
48,9	9,8
42,2	41,5
35,6	35,6
61,1	46,2
41,6	32

Excessive Idle (standing still > 5 min) %	Work Hours	Wait (< 5 min) hours
36,5	0,3	2,1
0	0,6	1,1
39,1	1,6	0,3
0,7	27,2	21,1
0	7,1	6,3
14,9	35,1	41,7
9,6	87,3	47,9

Excessive idle (> 5 min) hours	Average km/h work	Overall l/h (idle included)
1,4	8,8	16,2
0	NULL	7,8
1,2	NULL	21,8
0,3	5,5	6,7
0	6,2	8,3
13,4	23,1	20,3
14,2	NULL	9,4

L/h during work (idle excluded)	L/h when total idle	Fuel Total	Fuel Work
46,4	13,2	60,8	15,5
15,7	2,8	12,7	9,9
27,7	15,6	64,7	42
10,1	3	339,1	274,3
16,1	3,8	144,9	121
42,3	6,3	1831,1	1485,3
13,9	3	1402,8	1215,3

Fuel Idle (Wait < 5 min + Excessive Idle > 5 min)	Fuel Wait (standing still < 5 min)
45,3	26,8
2,9	2,9
22,7	3,1
64,8	63,8
23,9	23,9
345,8	262,8
187,3	144,5

Fuel Excessive Idle (standing still > 5 min)	CREXC L/h F-mode	CREXC L/h G-mode
18,5	NULL	NULL
0	8,2	16,7
19,6	16,6	30,5
1	NULL	NULL
0	NULL	NULL
83	NULL	NULL
42,7	NULL	NULL

CREXC L/h H-mode	CREXC L/h P-mode	CREXC Fuel F-mode	CREXC Fuel G-mode
NULL	NULL	NULL	NULL
18	0	0,9	3,8
28,8	23,4	3,3	17
NULL	NULL	NULL	NULL
NULL	NULL	NULL	NULL
NULL	NULL	NULL	NULL
NULL	NULL	NULL	NULL

CREXC Fuel H-mode	CREXC Fuel P-mode	CREXC Hours F-mode	CREXC Hours G-mode
NULL	NULL	NULL	NULL
5,2	0	0,1	0,2
20,8	0,9	0,2	0,5
NULL	NULL	NULL	NULL
NULL	NULL	NULL	NULL
NULL	NULL	NULL	NULL
NULL	NULL	NULL	NULL

CREXC Hours H-mode	CREXC Hours P-mode	CREXC F-Mode %	CREXC G-Mode %
NULL	NULL	NULL	NULL
0,3	0	18,3	35,9
0,7	0	13,1	36,7
NULL	NULL	NULL	NULL
NULL	NULL	NULL	NULL
NULL	NULL	NULL	NULL
NULL	NULL	NULL	NULL

CREXC H-Mode %	CREXC P-Mode %	WHEXC W L/h	WHEXC C L/h	WHEXC T L/h
NULL	NULL	NULL	NULL	NULL
45,8	0	NULL	NULL	NULL
47,5	2,7	NULL	NULL	NULL
NULL	NULL	NULL	NULL	NULL
NULL	NULL	NULL	NULL	NULL
NULL	NULL	NULL	NULL	NULL
NULL	NULL	8,1	0	0

WHEXC W Fuel	WHEXC C Fuel	WHEXC T Fuel	WHEXC W Hours	WHEXC C Hours
NULL	NULL	NULL	NULL	NULL
NULL	NULL	NULL	NULL	NULL
NULL	NULL	NULL	NULL	NULL
NULL	NULL	NULL	NULL	NULL
NULL	NULL	NULL	NULL	NULL
NULL	NULL	NULL	NULL	NULL
1215,3	0	0	149,8	0

WHEXC T Hours	Fuel Total/h score	Utilization % score	CO2_ACTUAL	Tonnes
NULL	182,2	4,9	0,15808	NULL
NULL	354,1	25	0,033134	NULL
NULL	313,7	23,3	0,168126	NULL
NULL	2437,7	3,6	0,88166	NULL
NULL	970	3,4	0,37674	NULL
NULL	860	5,9	4,76086	0
0	2124,7	4,2	3,647238	NULL

Tonnes/h	Tonnes/h during work	Tonnes/l	Tonnes/l during work
NULL	NULL	NULL	NULL
NULL	NULL	NULL	NULL
NULL	NULL	NULL	NULL
NULL	NULL	NULL	NULL
NULL	NULL	NULL	NULL
0	0	0	0
NULL	NULL	NULL	NULL

Average payload utilization	Number of overload occasions (of total)	Number of cycles
0	NULL	NULL
0	NULL	NULL
0	NULL	NULL
0	NULL	NULL
0	NULL	NULL
0	0	0
0	NULL	NULL

Number of cycles/min	Average cycle time (min)	Average cycle distance (km)
NULL	NULL	NULL
NULL	NULL	NULL
NULL	NULL	NULL
NULL	NULL	NULL
NULL	NULL	NULL
0	0	0
NULL	NULL	NULL