CHALMERS
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Surveying in the Construction Industry

A study of surveying and machine guidance systems in excavators on ground construction projects

Master's thesis in Architecture and Civil Engineering

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Master's Thesis ACEX30-18-60
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Cover:
Left figure: Excavator with machine guidance system (Author´s own copywrite)
Right figure: Surveyor in conversation with a construction worker (Author´s own copywrite)

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ABSTRACT

The technology of machine guidance is said to minimize the need of traditional surveying by allowing the machine operator to perform this with the construction machine. However, the system is often used parallel with traditional surveying. The aim of this thesis is to investigate if parallel work with machine guidance systems and surveying can be avoided and if so, how they can be used to minimize the double work. In addition, to examine how the roles of surveyors and machine operators have and will continue to change with the development of the systems. To fulfil the aim, a literature-, interview- and project study was performed to gain in-depth knowledge of the systems and different actors opinions regarding the system.

Firstly, it was found that an additional technical consultation insurance is needed when using machine guidance for surveying tasks. Moreover, some clients do not accept data from the system as documentation. From a technical perspective it was found that machine guidance with GNSS has low accuracy and do not comply with most tolerances. Systems using laser or total stations has better accuracies and comply with several tolerances. However, several actors have stated that there is a difference between what the systems can do theoretically and what can be achieved. Machine operators' knowledge affect the possibilities with the system and operators that are used to the systems can perform several surveying tasks. Still, surveyors will be needed for control measurements and some specific measurements that the machines are not able to perform. From a time and costs perspective it was found that some surveying tasks, for example measure in of an existing surface is too time consuming to perform with a machine guidance system and is recommended to be performed by a surveyor.

The roles of surveyors and machine operators have and will continue to change with the development of machine guidance systems. Surveyors will perform less measurements on the construction sites and more time on supporting work to the machine guidance systems. Moreover, machine operators get more responsibility when using machine guidance systems and will hence have a more important role in projects.

This thesis shows that double work with machine guidance systems and surveyors can be avoided to some extent. Machine guidance systems cannot be used for all surveying and hence is traditional surveying needed but to a lower extent than previous. In addition, a well-planned project where the work roles are well defined and with a machine operator who has good knowledge of the systems will contribute to avoiding double work.

Key words: Machine guidance, machine control, surveying, excavators

Mätteknik i anläggningsprojekt
En studie om mätteknik och maskinguidningssystem hos grävmaskiner i anläggningsprojekt

Examensarbete inom masterprogrammet *Infrastruktur och miljöteknik*

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SAMMANFATTNING

Maskinguidning är en teknik som kan minska användandet av vanlig detaljmätning genom att maskinföraren kan utföra utsättning och inmätning direkt med maskinen. Dock används systemen ofta parallellt med vanlig utsättning och inmätning idag. Syftet med detta examensarbete har varit att undersöka om dubbelarbeten med maskinguidning och mättekniker kan undvikas och om så är fallet analysera hur man kan använda teknikerna för att minimera dubbelarbetet. Därtill, att studera hur maskinförare och mätteknikers roller har och kommer att ändras i och med systemets utveckling. En litteraturstudie, intervjustudie och projektstudie har genomförts för att få djupare kunskap om maskinguidning och detaljmätning, samt information om olika aktörers åsikter om maskinguidning.

Arbetet visar att en teknisk konsultförsäkring behövs för att mätningsarbetet med maskinguidningssystemet ska täckas samt att alla beställare inte accepterar data från systemen som underlag. Från ett tekniskt perspektiv framkom att GNSS-baserade maskinsystem har en låg noggrannhet och uppfyller inte de flesta byggplatstoleranserna. System med laser eller totalstation har högre noggrannhet och uppfyller toleranserna för flera objekt. Dock är det inte systemens noggrannhet som begränsar användandet utan kunskapen hos maskinisterna. Maskinister som är vana vid systemen kan utföra det mesta av utsättningen och inmätningen. Mättekniker kommer fortfarande behövas för kontrollmätningar och vissa detaljmätningar som maskinen inte kan utföra. Från ett tids- och kostnadsperspektiv har det framkommit att vissa mätningsarbeten är för tidskrävande att göra med maskinen, till exempel inmätning av en befintlig yta. I dessa fall rekommenderas det att en mättekniker genomför mätningarna.

Mätteknikers och maskinförares yrkesroller har och kommer att fortsätta förändras med utvecklingen av maskinguidning. Mättekniker kommer utföra färre mätningar på byggprojekt och mer tid på kontoret med arbeten rörande maskinguidning. Maskinförare får ett större ansvar i projekt och därav få en viktigare roll.

Arbetet visar att dubbelarbete mellan maskinguidning och mättekniker kan undvikas till en viss grad. Maskinguidning kan inte användas för alla mätningsarbeten och traditionell detaljmätning kommer fortfarande behövas, men till en lägre grad än tidigare. Dock är en noggrann planering av arbetsfördelningen och maskinister med god kunskap om systemen och detaljmätning viktig. Kunskap och planering är grunden för att undvika dubbelarbete och spara tid och kostnader.

Nyckelord: Maskinguidning, maskinstyrning, mätteknik, grävmaskiner

Contents

Preface

This master thesis is the concluding part of my studies at the program of Infrastructure and Environmental Engineering at Chalmers University of Technology.

I would like to acknowledge and thank some of the people that have helped me along the way. The first ideas for the thesis was presented by Andreas Bladh, whom I would like to thank for an educational and interesting topic. I would also like to thank my supervisor Anders Markstedt for advice and guidance during the work and my examiner Gunnar Lannér. Furthermore, the thesis was performed on behalf of Peab Asfalt and I would like to thank Johan Gustafsson, Henrik Johansson and Ola Sandahl at Peab Asfalt for support and help during the work. Tobias Rydén and Emil Hjertberg from Trig have given me interesting insights from surveyors' perspective on the topic and it has contributed a lot to the work. Rickard Juhlin from Leica Geosystems have helped me with questions regarding machine guidance systems which have been of great help. David Gullberg at WSP contributed with his perspective as a previous project planner. Moreover, I would like to thank Sebastian Henriksson from SG Maskin for his insights as a machine operator and Babak Mobaraki at Länsförsäkringar for his help with questions regarding insurances. Finally, I would like to thank Adam Dahlin, Sandra and Stefan Schleeh, Stina Lundin, and Tomas Selldén for constant support during the work.

Gothenburg, May 2018

Desirée Persson

Conceptual Explanations and Abbreviations

Accuracy	*A term indicating the measurements spread around the true value. However, in geodetic measurements are the true value of a measurement not known.*
AMA	*A Swedish reference book with general material- and work descriptions for the construction industry.*
GNSS	*Global Navigation Satellite Systems*
Machine control system	*A system in construction machines allowing the operator to perform some surveying measurements. The systems are automated, so the measurements control the machines hydraulics.*
Machine guidance system	*A sort of machine control system without automation of the hydraulics. The system only guides the operator to the correct position or level.*
Mean deviation	*A term commonly used for expressing the variations from a true value. Accuracy is often expressed as some type of mean deviation.*
Measuring and compensation rule	*Used when all or some objects in projects are adjustable and compensated for according to the real volumes, items and lengths etc. Described in a supplementary book to AMA that specify how different objects or works should be measured and compensated for.*
Measuring in	*The process of determining point´s position in plan and/or elevation, relative to other position determined points*
Precision	*A term to describe measurements variation from the mean value of the measurements, i.e an unknown value. Also called standard deviation.*
Prime meridian	*The longitudinal zero plane in a geocentric coordinate system. Traditionally it refers to the Greenwich meridian. For satellite measurements it refers to the IERS reference meridian.*
Record drawing	*Drawing submitted by a contractor upon completion of a project. The drawings show the changes made during the construction process.*
Setting out	*The establishment of temporary reference markings in the terrain such as pegs, lines and levels that are needed for construction.*
Surveying	*I.e Engineering surveying. Surveying traditionally refers to determining the three-dimensional position of points on or near earth's surface by measuring distances and angles. But in modern terms is surveying*

	defined as the collection, processing and managing of spatial information.
Surveyor	*A person whose occupation is surveying. The tasks include for example setting out, and measuring in.*
Terrestrial measurements	*Measurements performed on the surface of earth.*
Tilt	*A function on some excavators allowing the bucket to be angled in several different directions relative to the boom.*
Trueness	*A term describing the compliance with the measurements mean value and the true value*.

1 Introduction

The society has gone through a large digitalisation process in the last decades. (Svensk Byggtjänst, 2017b) Several sectors have gained more efficiency from this compared to the civil engineering sector, especially the construction industry. The construction industry has been more conservative and has not fully implemented all available techniques. For one instance the technology of machine guidance systems, are systems that have shown real progress in the surveying field (Fosburgh, 2011). Machine guidance systems allows the operator to see the drawings on a screen and the machine can automatically tell when it is positioned in the correct position or level (Granhage, 2011; Schofield & Breach, 2007). However, the construction industry is relatively new to this area and several benefits are yet to be discovered and the question of how to use it needs to be investigated more (A. Bladh. personal communication November 17, 2017).

1.1 Background

When performing ground construction work, several actors might be involved. Such as:

- Machine operators who drive the construction machines
- Construction workers who perform manual construction tasks for example lay pipes or cables.
- Supervisors who manage the daily or weekly tasks, give updates of the construction plans, and control the progress.
- Surveyors who perform measurements and set out markers that show lines, heights or points that are used for guidance when performing the construction.

Traditionally the surveyors were on site every working hour to perform measurements supporting the construction workers and machine operators but today after the arrival of machine guidance systems, their presence are varying. Peab Asfalt uses machine guidance system on larger ground constructions today and often are both machine guidance systems and manual surveying used parallel in projects. Hence, sometimes is the same work done twice and this parallel work leads to unnecessary use of time on surveying, which result in a waste of time and costs. Peab Asfalt are therefore interested in how surveying and machine guidance systems could be used in ground construction projects.

1.2 Aim and objectives

The aim of the master thesis is to investigate how manual surveying and machine guidance systems can be used on ground construction projects to reduce parallel work, gain efficiency, and save costs in the building processes. The objectives are to:

- Analyse if and why parallel work between surveyors and machine operators occur
- Investigate if parallel work by machine guidance systems and surveyors can be avoided.
- If so, investigate how machine guidance systems and manual surveying can be used on ground construction sites to avoid parallel work.
- In addition, examine how the roles of surveyors and machine operators have and will change with the development of machine guidance systems.

1.3 Limitations

The thesis is focused on the use of surveying and machine guidance systems on ground construction projects. Ground construction projects include for example; ground preparations for foundations of buildings, laying of cables and pipes, and road construction. In addition, the focus is towards detailed surveying, and hence the tasks of setting out and measuring in.

The machine guidance systems are analysed for implementation in excavators and the investigation is focused at four topics; regulations and insurances, technical aspects, knowledge, and time and costs. For regulations and insurances, the focus is if machine guidance systems are accepted for performing surveying tasks. For the technical aspects, the machine guidance systems accuracy is compared to tolerances for setting out and measure in on construction sites. The tolerances for setting out were collected from HMK Bygg & Anläggning BA 4 and for measure in, the values were collected from HMK.Ge-D, appendix F. These books have been assumed to be valid when tolerances are not stated in the construction documents.

Furthermore, the aspect of knowledge is based on interviews where different actors have stated that it is not suitable to use machine guidance systems due to lack of knowledge among the machine operators. The aspect of time and costs is also based on information from interviews where different actors have stated it to be more time consuming, hence costlier to use the machine guidance system rather than traditional surveying.

The interview study has been limited to focus on the perspectives of a surveyor, company developing machine guidance systems, project planner, site manager, machine operator and a corporate adviser on insurances.

1.4 Outline of thesis

The thesis is divided into 12 chapters where chapter 2 present the methodology and implementation of methodology for the thesis. Chapter 3 present previous research on similar topics and this thesis connection to the research. Furthermore, chapter 4 presents the main occupations on small construction projects and their traditional work tasks. The information in chapter 4 will be used for examining how the roles of surveyors and machine operators have or will continue to change with the development of machine guidance systems. Moreover, chapter 5 introduces surveying including the geodetic infrastructure, reference systems, and GNSS systems. The information given in the chapter gives a broad base of geodesy and surveying that is needed for understanding the complexity of surveying tasks.

Furthermore, chapter 6 and 7 respectively presents the theories regarding detailed surveying with manual surveying and machine guidance systems. The chapters include the systems function, in-data, operation processes, instruments, accuracy and sources of errors and limitations. Additionally, chapter 8 presents the theory regarding tolerances in construction projects. The chapter present examples of tolerances that later is used for analysing the technical aspect of the system, which is presented in chapter 10.

Chapter 9 present the results from the interview study where surveying and machine guidance systems are investigated from different actors' perspective. Chapter 11 present the case study and its findings. Lastly, the thesis is ended with a discussion, chapter 12, and conclusions, chapter 13.

2 Methodology

There are several methods for investigating different topics and different methods are better suited for certain types of research questions. To fulfill the aim of this thesis, a qualitative method has been chosen. Qualitative methods can be used for answering questions related to humans' opinions and thoughts regarding different questions or topics. (Hedin, 2011) A qualitative study can be used exploratory when only little is known about the topic or question in advance. The aim of a qualitative study is to get a broad and accurate description of the topic. The data collected in a qualitative study is represented in words rather than numbers (Hedin, 2011; Svensson, 2015).

A qualitative study is often performed with semi-structured interviews (Hedin, 2011). The interviewer has a list of questions to the interviewee, but the order of the questions can be changed, and questions can be removed or added during the interview (Svensson, 2015) The interviews are adapted to the interviewees knowledge, interest and background. Only a small number of people are involved in the study, usually five to ten persons, but the interviews are performed more in depth. (Hedin, 2011) Since the aim of a qualitative study is to get a broad view, it is recommended that the people interviewed are as different as possible. It is also recommended to consider choosing people that will have a lot to contribute to the study.

When performing a qualitative study, it is recommended to use several methods to get a broad view of the topic. (Hedin, 2011) This is also recommended for validating the opinions and thoughts collected during the interview and hence increase the credibility of the study. A project study is therefore of interest to investigate how machine guidance systems are used today and what errors and problems usually occur. In addition, to test some of the systems functions while minimizing the manual surveying, to investigate how the system can be used.

Case studies are used for gathering more in-depth knowledge of the area of interest. (Svensson, 2015) It highlights the unique, increase the opportunity to concretize, modify established truths and describe links between different people or groups. However, case studies can be harder to generalize.

When performing interviews, usual errors are that questions are unclear, the interviewee misunderstands a question, the interviewee remembers incorrect, the interviewer registers the answers incorrect and that the information is processed or analyzed incorrect. To minimize the risk of errors should the interviewer be well prepared and engaged in the topic, be structured by having presented the aim of the interview and the study, have clearly stated questions and show consideration and not interrupt the interviewee. In addition, it is important that the interviewer is open and react to the important things to direct the interviewee to the topics of interest of the study. The interviewer should also be critical and questioning. Another concern with interviews are that the reliability must be questioned, and people have different ability to express themselves in speech. Moreover, the interest will vary, and hence will the selection be skewed.

As previously mentioned, the interviews will be accompanied with a project study to validate the interviewees opinions and thoughts and also to get a broader view of the topic. Additionally, a literature study will be performed to get engaged in the topic and prepare for the interviews.

When performing a literature study, it is important to consider the written materials authenticity, credibility, representatively, and meaningfulness. (Svensson, 2015) These aspects can be checked by thinking of the following questions:

- Is the material genuine?
- For what purpose was the material written?
- Does errors occur in the material?
- What primary and secondary sources have been used?
- Does other material tell the same thing?
- Is the material intelligible?

When performing a qualitative study is the overall quality of the research guaranteed by:

- Perspective awareness – The author has presented and discussed its pre-understanding of the topic. (Svensson, 2015)
- Internal logic – The correct analysis method has been chosen and the method has been motivated. (Svensson, 2015)
- Good quality of data – Quotes from informants support the result. (Svensson, 2015)
- Legitimacy – The steps to the conclusions are clearly stated. (Svensson, 2015)

2.1 Implementation of methodology

To fulfil the aim of the thesis, the project was planned to follow the workflow;

A literature study was initially performed on manual surveying and machine guidance systems in order to understand the techniques behind the systems, their function, need of data, and their measurement uncertainty. The information was collected from books, institutions, organizations, and product developers. The literature study provided a base for the continuing work with interviews and project studies.

The interview study was performed to get a broad and thorough understanding of surveying and machine guidance systems. Since a broad understanding was aimed at, the interviewees were strategically chosen and several actors from the construction industry was interviewed. Interviews were initially held with a surveyor, a developer of machine guidance systems, project planner, a site manager, and an operator of an excavator. The interviews were performed to understand how the systems are used today, how the actors want to use the systems, the requirements when using machine guidance systems, the systems development potential, and lastly the systems costs, benefits, and limitations. During the interviews were topics regarding regulations and insurances brought up and an additional interview was held with a corporate adviser on insurances. The interviews were performed as semi-structured qualitative interviews where questions were prepared beforehand. During the interview were the questions sometimes adopted to the interviewees background, knowledge, or interest. The list of questions for the interviews are shown in appendix A.

A case study was planned to investigate how machine guidance systems are used today and what errors and problems usually occur. In addition, the project study aimed at investigating how the system can be used when minimizing manual surveying. However, the project was delayed and hence was the project study only used for information regarding how the system have been used / are planned to be used.

3 Former Research

Machine guidance systems have been an area of interest for the construction industry for a couple of years. Theses, prior to this have been investing different topics related to machine guidance and this chapter will present some of these studies.

3.1 Satellite guidance of excavators

Henric Jonsson performed a graduation project regarding satellite guidance of excavators at Luleå University of Technology in 2008. (Jonsson, 2008) The project aimed at investigating if GNSS based machine guidance systems provided more benefits than costs and how the systems affect the production and actors involved in a construction project. In addition, it aimed to give examples of excavations of where it is suitable to use the systems.

The method for the project was to perform a literature and interview study. (Jonsson, 2008) The author interviewed surveyors, machine operators, site managers, construction engineers, a foreman, construction workers, a developer of machine guidance systems, and owners to an excavator and transport company.

The conclusions were that the system provides more benefits than costs. (Jonsson, 2008) In addition, machine guidance systems were suitable for all types of excavation work except for fine planning and on projects where surfaces should be connected to existing surfaces. For large projects where a large surface is to be excavated, simpler systems with for example laser is recommended. The projects that gain most from using machine guidance systems are large projects where the ground surface have several slopes at different directions, large foundation works, road and railroad works, and pipe and cable excavations. At foundation works, the machine operator can perform the tasks alone until refill and compaction of the area is needed, then a construction worker is needed. When performing pipe and cable excavations, the system allows for a more efficient building process. The construction worker can place ground cover sheets, lay pipes, and refill the excavation parallel as the machine operator continue the excavation.

It was concluded that a structured and well-planned project was important when using machine guidance. (Jonsson, 2008) Four topics were brought up;

1. The construction documents should be finished in time.
2. The surveyor should be allowed time to create the models or files necessary for the construction.
3. Installation, set-up, and control of necessary equipment should be performed before the start day of the project.
4. Personnel with knowledge of the systems and the files should be available on the first day of construction, to allow for fast help if problems occur.

It was added that traditional 2D drawing should be available in projects, so the construction workers can perform their tasks, despite the lack of guidance markings from surveyors.

According to Jonsson, the surveyors are affected the most when implementing machine guidance systems. Previously, their work tasks were mainly performed at the construction sites but with machine guidance systems there are more tasks performed by the computer; creating models, perform mass and quantity calculations and create as-built drawings. The tasks of measuring in and control measurements are still performed by surveyors. However, Jonsson stated that the task of measuring in likely would be performed by the machine operator in the future. The machine operators also get a changed working environment. Their work tasks become more independent, they get more insight in the construction project, and they perform the main setting out and get more responsibility. From the interviews it was concluded that the machine operators are positive to the responsibility but feel that the other actors rely too much on the systems. The other actors assume that the machine operators can take over more of the surveyors and construction workers work tasks than they are comfortable with. The third actor affected by the usage of machine guidance systems are the construction workers. When using machine guidance systems, the construction workers are not needed side by side with the excavator, and it allows them to plan their work tasks better. In addition, they are affected by that less markings are used on construction sites and need to study the drawings more than before.

3.2 GPS machine guidance in construction equipment

Daði Hrannar Aðalsteinsson performed a final project regarding GPS machine guidance in excavators in 2008. (Aðalsteinsson, 2008) The aim of the project was to compare the performance of an excavator with and without a machine guidance system. A construction job was performed to analyse the differences in performance. For the excavator without machine guidance, a surveyor was on site before the job was performed, and later the machine operator performed the job after the measurements and markers set out by the surveyor. The excavator with a machine guidance system performed the job without any surveying job but according to a model of the project. Both constructions were monitored with precise measuring equipment to allow a comparison of productivity, material and time.

The conclusions were that machine guidance systems improve the construction performance by minimising excavation errors, resulting in extra masses or having to redo the work and excavate more. Both time, fuel, and extra material for additional filling is saved, and hence also costs. In addition, the transportation for extra filling material or unnecessary excavation largely diminished. The author ended the conclusions by adding that machine guidance systems optimize the excavation work, increase production rate, lower costs and has a satisfactory accuracy.

3.3 Profitability with machine control

Henrik Lenartsson and Simon Åberg performed a degree project regarding profitability when using machine control systems in 2009. (Lennartsson & Åberg, 2009) The main aim of the project was to investigate if machine control systems in excavators, dozers and graders provide savings in projects compared projects do not using the systems.

It was concluded that it is profitable to use machine guidance systems, when comparing the costs between projects using and not using machine control. Projects not using machine control systems requires a surveyor and an extra construction worker to work alongside the machine, resulting in high costs. When using machine control systems might a surveyor or an extra construction worker only visit the site for some hours during the day. In addition, the cost for the system is less than the costs for the additional workers when not using the system. Initially might the progress rate be slower when starting to use the technique, since the machine operator needs to learn the system, but in the long perspective will the progress rate increase.

Moreover, the traditional surveying tasks should not be forgotten since some project might not be able to use machine control systems. Machine guidance systems will continue to develop, and it requires a good knowledge by both surveyors and machine operators. In general, machine control systems will ease the surveyors and machine operators' tasks and make the production more efficient.

3.4 Machine guidance on small road constructions

Malin Berntsson wrote a thesis regarding machine guidance systems on small road construction as her graduation project at Chalmers University of Technology in 2011 (Berntsson, 2011). The aim of the thesis was to provide material for decision making related to machine guidance at the construction company NCC. It included what requirements the different actors in a construction project had, what investments that were needed before using a machine guidance system and an investigation of when machine guidance were economically defendable on small ground construction works. In addition, the aim was to highlight the dialog needed between the actors in a construction project using machine guidance and examine how it could be improved.

It was concluded that the main factor affecting the possibility to use machine guidance on a small construction site was the costs and the limited knowledge. However, the costs for the systems would probably decrease, allowing the system to be used on smaller projects within a couple of years. It was concluded that machine guidance with GNSS and traditional setting out was the most suitable system since the costs were lower than for systems using total stations. The recommendation was to continue with traditional setting out and temporary marking to ease the work of the machine operators and construction workers, but to a lower degree.

It was also concluded that education was needed and that an inventory of knowledge prior a project is recommended, to see if the managers of the project have enough education. NCC has a course regarding planning when using machine guidance systems in a project. The preparations were a five-day process where day one contained checking the drawings and files for the system, checking the equipment and arrange for the adjustment needed. Day two contained measuring in of existing surfaces and setting out. Day three to five contained delivery of machines, installation of systems (when needed), control of the systems, and transferring of files and models to the systems control box.

3.5 Possibilities and limitations of GNSS instruments in road constructions

Rickard Johansson and Torbjörn Öster performed a Master degree project in 2011 which focused at possibilities and limitations when using GNSS technology in road constructions for setting out, mainly in respect of tolerance requirements. (Johansson & Öster, 2011) The project was performed through a literature study for gathering information regarding tolerances on road constructions and the accuracy of different measurement methods. In addition, interviews and a questionnaire were performed to get information regarding equipment and methods used, actors' perspective on the methods, and the knowledge of GNSS techniques among contractors.

The conclusions were that costumers using AMA anläggning when producing the project documents will give tolerances for the different objects in the construction. Furthermore, GNSS technology has to high uncertainties and do not comply with tolerances in road constructions. However, in the interviews contractors stated that the GNSS technology can meet the tolerances for the unbound layers except the base coarse adjustments. In addition, it was concluded that the knowledge regarding GNSS technology was good amongst contractors working mainly with major road constructions. There are several benefits with using GNSS technologies for example that it gives the machine operator a good overview of the projects and time savings. The main disadvantages are poor compatibility between brands, that other actors have hard to visualise the project when no markers are used, and inaccuracy which means that the traditional equipment still is needed.

3.6 Machine control and its use from a geodetic perspective

Caroline Carlsson and Matilda Tidholm (2013) wrote a thesis regarding machine control systems as their graduation project at the Land surveying and Cartography program at Karlstad University. The project aimed at understanding how machine control systems affected the construction industry. In addition, it aimed to investigate the use of GNSS based machine control systems as an instrument for setting out and compare it with traditional setting out with a total station.

The method for the thesis was to perform a literature study, interview study, and a field test where setting out with a machine guidance system and total station was performed. The field test comprised of that five points were to be set out, then setting out was performed with first a machine guidance system and the point was market with steel bars in plan and electrical tape in height level. Further on, setting out was performed with a total station and the data was then analysed and compared.

It was concluded that the accuracy of machine guidance systems was less than the accuracy of total stations. When analysing the points heights were four of five point, set out with machine guidance within the requirements from the client. Only three of five points had the same or better accuracy than stated by the manufacturer. Moreover, when analysing the points position in plan, only one of five points were within the requirements from the client. However, it was concluded that the calibration was wrong, and the system was only calibrated for height measurements.

3.7 The thesis connection to previous research

From the research of previous theses, it should firstly be noted that the theses with similar focus on machine guidance as this thesis were produced five to ten years ago. The machine guidance systems have developed since then, and the actors have used the systems for a longer time, resulting in that the questions in this thesis are of interest despite the previous research. The aims of the previous theses have been different from this thesis main aim; to investigate how machine guidance should be used to minimize the parallel work by surveyors and machine operators. The other theses have focused at the systems profitability, when to use the systems, tolerances and the systems measurement uncertainty as well as the systems effect on actors within the construction industry.

Previous research by (Aðalsteinsson, 2008; Jonsson, 2008; Lennartsson & Åberg, 2009) has concluded that machine guidance systems are profitable to use, since both time and costs are saved. In addition, the systems are used to a high extent today, and hence have the question of profitability and when to use the systems not been of interest for this thesis.

The research by (Aðalsteinsson, 2008; Carlsson & Tidholm, 2013; Johansson & Öster, 2011) focused on the systems accuracy and the results were varying. (Aðalsteinsson, 2008) concluded that the system had a satisfactory level of accuracy for pipe excavations. (Johansson & Öster, 2011) initial literature study of tolerances at road constructions and of the systems accuracy indicated that the system had to high uncertainties. However, according to interviews. the accuracy of machine guidance systems were acceptable for most unbound layers in road constructions. (Carlsson & Tidholm, 2013) Research indicated that the accuracy of machine guidance systems was lower than stated by the manufacturers, however was parts of the tests invalid due to calibration errors. Since the research were performed five to ten years ago, the question of the systems measurement uncertainty is still of interest. The systems accuracy might have changed with the development of the systems. In addition, it is an important factor when analysing which tasks a surveyor should do and what a machine operator can do.

The questions of the systems effect on the different actors in a construction project is highly related to this thesis main aim and what the different professions should or can do. The conclusions drawn in the previous research is of interest but the time since the theses were produced affects the reliability of the information. Therefore, it has only been used for inspiration for the literature study and interview study.

4 Occupations in Construction Projects

Several occupation categories are needed in a construction project. (Byggledarskap, 2014) In general, the professions can be divided into two parts: professional workers and the staff management. The professional workers are the workers that perform the practical building and construction tasks while the staff management are responsible for planning, economy, and staff. Another category exists; officials, that provides support for staff management and the construction project. However, this chapter will focus on the professional workers and the staff managements roles.

4.1 Staff management

The staff management on smaller ground construction project often consist of a site manager, a supervisor, a construction engineer, and a surveyor. Larger projects might have additional workers, but these will not be presented (Byggledarskap, 2014).

4.1.1 Site manager

The site manager is responsible for the production at a construction project (Peab, 2018). The responsibility includes planning, economy, execution, and managing of staff and subcontractors (Byggledarskap, 2014). In addition, the site manager is responsible for quality-, environmental- and working environment plans on a project (Peab, 2018). The site manager is in legal terms the employer's representative with responsibility for works and personnel as well as economy of the project. (Byggledarskap, 2014) The site manager often has a supervisor subordinated.

4.1.2 Construction engineer

The construction engineer acts as a support function to the site manager. (Byggledarskap, 2014) The construction engineer and site manager has shared responsibility of the project management and economy monitoring on projects. The construction engineer is responsible for the projects document management and the administrative work. (Byggledarskap, 2014; Peab, 2018) The work tasks include for example: preparation of production calculations, final reconciliations and cost follow-ups, creation of change, supplementary and outgoing works. On smaller construction project can the construction engineer also be responsible for purchasing, and planning (Byggledarskap, 2014).

4.1.3 Supervisor

The supervisor is subordinated to the site manager and is responsible for the daily or weekly production planning as well as management on the construction site. (Byggledarskap, 2014) The supervisors work tasks usually include; control of machines and material, controlling that the work is performed according to the drawings and instructions, control that the quality- environmental, and working environment plans are followed, and coordinate the work with the subcontractors.

4.1.4 Surveyor

A surveyor perform measurements on construction sites to either mark points in the terrain to guide the construction workers and machine operators in their work or to measure in constructed objects and produce drawings of the constructed objects (Peab, 2018). The surveyor has a major responsibility in the construction project and the main aim is to guide and help the professional workers in the construction (Byggledarskap, 2014).

4.2 Professional workers

On smaller ground construction projects does the professional workers consist of construction workers, and machine operators.

4.2.1 Construction worker

A construction worker perform different field works which vary greatly depending on the project or work area (Byggledarskap, 2014). The work tasks include a range of tasks for example; laying asphalt, laying pipes and cables, perform foundation work for simpler outdoor structures such as benches and playground equipment, construct lawns or perform stone paving surfaces (Arbetsförmedlingen, 2017a). The work includes using various types of machines and instruments for example, cutting tools, vibratory plate compactors and measurement instruments (Peab, 2018).

4.2.2 Machine operator

Machine operators drive different machines on construction projects that is used for example excavation, loading and unloading. (Arbetsförmedlingen, 2017b) The work mainly involves operating the machines, but sometimes it involves assisting the construction worker with for example compacting filled material with a plate compactor. Therefore, must the machine operator also have good knowledge of the construction workers tasks.

5 Geodesy and Surveying

Geodesy is defined as the study of earths geometric size and shape, exact position of points on its surface and the science of its gravity field (Merriam Webster, 2018). In the civil engineering sector geodesy is often associated with geodetic measurements and engineering surveying, henceforward referred to only as surveying (Granhage, 2011). As a surveyor, the knowledge of geodesy is crucial, it is the foundation of surveying (University of New Brunswick, 2018; Uren & Price, 2010). Surveying traditionally refers to determining the three-dimensional position of points on or near earth's surface by measuring distances and angles (Jack McCormac, 2004; Walker & Awange, 2018). However, with the development of new technologies such as GNSS systems and machine guidance systems, the definition has changed (Uren & Price, 2010). In modern terms, surveying is defined as collection, processing and managing of spatial information (Uren & Price, 2010; Walker & Awange, 2018). Geodetic measurements and surveying are broad terms which includes several measurement categories which can be divided in more than one way;

Firstly, the measurement categories can be divided based on how the measurements are performed; terrestrial measurements or GNSS measurements. (Lantmäteriet et al., 2013) Until some decades ago were almost all geodetic measurements terrestrial measurements, meaning that the measurements were carried out on the surface of earth. However, the development and availability to satellites made it possible for satellite positioning, so called GNSS positioning and today is GNSS surveying the most common method.

Secondly, surveying can be divided depending on the purpose of the measurements; control survey and detail survey (Lantmäteriet et al., 2013). A control survey is a survey where fixed reference points are established in a grid that later is used as a reference when performing detail surveying (Granhage, 2011). Detail surveying includes two categories; measuring in and setting out. Measuring in is the process of determining point´s position in plan and/or elevation, relative to other position determined points (Riksterminalbanken, 2017). Setting out refer to the establishment of temporary reference markings in the terrain such as pegs, lines and levels that are needed for construction (Granhage, 2011; Uren & Price, 2010).

Surveying requires a reference system and as previously mentioned can detailed surveying use a grid with fixed reference points for referencing point´s location. (Granhage, 2011; Lantmäteriet et al., 2013) These grids are called reference networks and are together with coordinate systems used for expressing a point´s location. (Lantmäteriet et al., 2013) Hence, a third division exist based on the reference- or coordinate system used. Traditionally, with terrestrial measurements were the measuring divided in the categories: plane surveying with two-dimensional coordinate systems, and height surveying performed in one-dimensional coordinate systems. But with the increased use of GNSS technology has another category developed; geodetic surveying. Geodetic surveying is performed in three-dimensional coordinate systems.

5.1 Geodetic Infrastructure

As previously mentioned does surveying require a reference system (Lantmäteriet et al., 2013). A reference system is implemented through a reference network that can be either passive or active. (Lantmäteriet, 2017d) Passive networks are grids with fixed reference points marked in the terrain that have been determined in plane, elevation and gravity trough detailed measurements (Lantmäteriet, 2017d; Samuel A berg, 2011). Since the earth is in constant change due to for example the continental drift, and uplift from the post-glacial rebound is it important to continuously monitor the movements and calculate its impact on the reference systems. (Lantmäteriet, 2017d) Additionally, the usage of satellite technology has also contributed to a new type of reference system; active systems. Active reference systems are characterised by a continuously monitored grid by permanent reference stations and that the measured data is directly transferred to the user. In Sweden one example of this is the active national reference system SWEPOS.

The shape of earth has a central role in surveying and reference systems since the tasks of measuring in and setting out is linked to either points on earth's surface or close to it (Lantmäteriet, 2017d). To explain a point´s position on earth are coordinate systems used. The terms reference system and coordinate system differ in that a coordinate system describe not only what reference system is used but also which coordinate format that is used. (Lantmäteriet, 2017a) Within the same reference system can a point be located at different locations depending on which coordinate system is used.

Since the earth has an uneven surface it is inappropriate to use it to create a coordinate system. Hence two types of surveying can be performed; plane surveying or geodetic surveying (Walker & Awange, 2018). Plane surveying sees earth's surface as a flat horizontal plane and the vertical is taken perpendicular to the plane. In contrast, geodetic surveying use a curved surface to explain earth's surface. The curved surface is a mathematical earth model, a so-called earth ellipsoid. The ellipsoid is one of three fundamental surfaces in the geodesy that are used to describe the earth. The other two are the surface of earth, and the geoid, see Figure 1 (Lantmäteriet et al., 2013). The surface of earth consists of the mean sea surface and elsewhere the physical surface of earth, and it differs ±10,000 meter in altitude. The geoid is the mean sea-level and the level the sea would have if it would continue under the continents. The ellipsoid is the mathematical model that best connect to the geoid and the difference between the geoid and the ellipsoid is around ± 100 meters. Geodetic surveying is used for GNSS positioning and can be used for surveying on global or national scale (Walker & Awange, 2018).

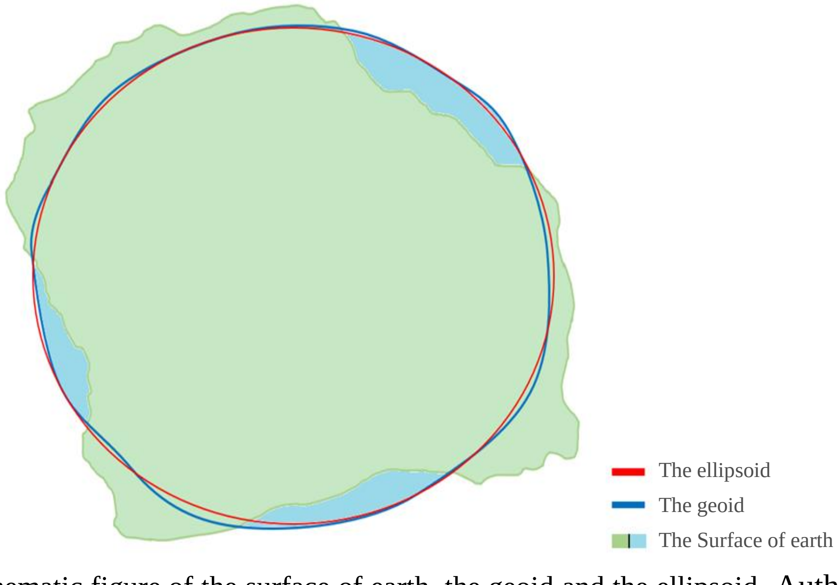

Figure 1. Schematic figure of the surface of earth, the geoid and the ellipsoid. Author´s own copyright.

5.1.1 Coordinate systems in one-, two- and three dimensions

Plane surveying uses one- and two-dimensional coordinate systems. (Lantmäteriet, 2017a) The two-dimensional coordinate system is used to define a point position in the horizontal plane and as previously mentioned does plane surveying define the earth's surface as a flat horizontal surface. (Uren & Price, 2010) This is done to simplify the calculation of a horizontal position. Plane surveying is suitable for smaller areas, less than 10-15 km in the extent in any direction (Uren & Price, 2010). One-dimensional coordinate systems, height systems are the foundation of specifying points' vertical position. (Lantmäteriet et al., 2013) As previously mentioned does three fundamental surfaces exist within geodesy; earth's surface, the geoid and the ellipsoid. The difference between earth's surface and the two other fundamental surfaces is of interest within surveying and hence does two height systems exist; the height over the geoid and the height over the ellipsoid.

For areas larger than 10-15 kilometres in extent does earths curvature need to be considered and therefore is geodetic surveying with three-dimensional coordinate systems recommended (Uren & Price, 2010). There are two coordinate systems to express coordinates in three dimensions, cartesian geocentric coordinates and geodetic coordinates. (Lantmäteriet, 2017a; Lantmäteriet et al., 2013) In the geocentric coordinate system is the origin located at the centre of earth and a point is expressed in terms of X, Y, and Z coordinates, se Figure 2. The Z axis is located along earth's rotation axis and intersect the north and south pole. The X- and Y axis form the equatorial plane where the X axis intersects the Greenwich meridian and the Y-axis completes a right-oriented system.

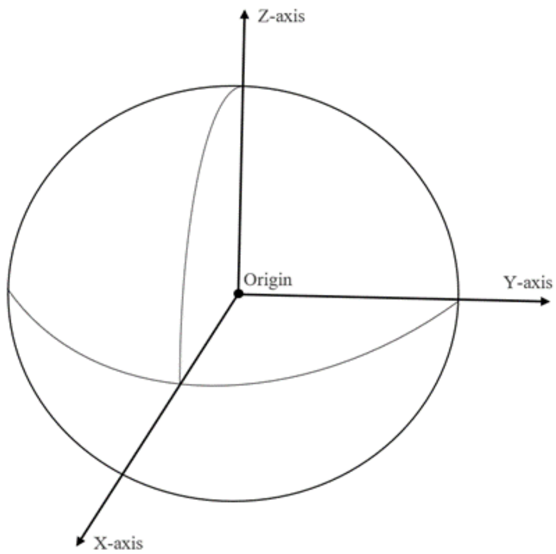

Figure 2. Schematic figure of a geocentric coordinate system. Author´s own copyright.

The geodetic coordinate system express points in terms of latitude, φ, longitude, λ, and height over the centre of earth or the ellipsoid, h, see Figure 3. Latitude is the angle in the north-south direction and latitude zero is in the equatorial plane (Lantmäteriet, 2017a). Longitude is the angle in east- western direction and has longitude zero at the prime meridian. The angels are given with the indicators north, N, south, S, east, E, and west, W depending on the angles direction form the zero planes.

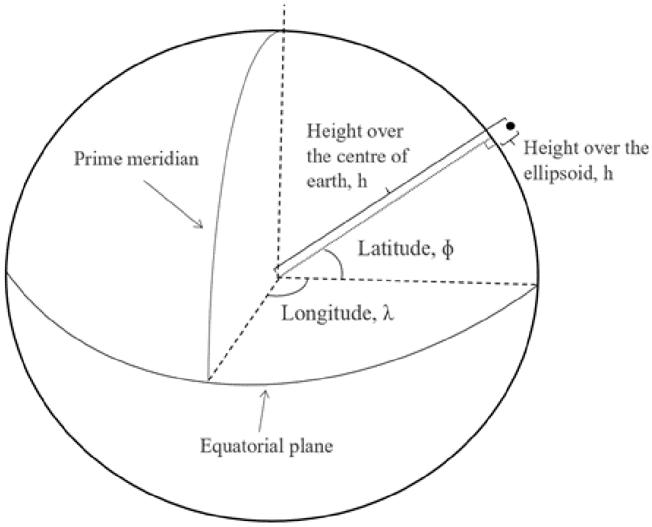

Figure 3. Schematic figure of a geodetic coordinate system. Author´s own copyright.

5.1.2 Reference systems

Reference systems can be global, national or small municipal reference networks and often are the networks dependent and based on each other. (Lantmäteriet, 2017a; Lantmäteriet et al., 2013) The national three-dimensional reference system in Sweden is SWEREFF 99 which is based on the European reference system; European Terrestrial Reference System 1989, ETRS, and subsequently on the International Terrestrial Reference system, ITRS. The reason for not having one global reference system is due to earths unstable surface caused by continental shifts, and land uplift etc. (Lantmäteriet et al., 2013). These changes are a few centimetres a year and therefore must the most accurate systems be constantly updated to be precise enough.

SWEREFF 99 is realised and monitored with the national active reference system SWEPOS (Swepos, 2018). In total does SWEPOS consist of 300 reference stations, and 21 of these are fundamental reference stations used for realising and monitoring SWEREFF 99. The stations are continuously monitored with GNSS receivers, to know their position in-real-time. When using the measurement data from these systems can the measuring in and setting out be performed with an measurement uncertainty better than centimetre-level (Lantmäteriet et al., 2013).

The need of three-dimensional reference systems have increased with the use of GNSS positioning (Lantmäteriet, 2017a). When using GNSS positioning can either SWEREFF 99 or the World Geodetic System 1984, WSG84, be used. (Lantmäteriet, 2018j).

The national one-dimensional height system in Sweden is RH 2000 which is realised through around 50,000 fixed points on the ground. (Lantmäteriet, 2018g) Uniform national reference systems will in the long-term result in lower costs and Sweden has adopted SWEREFF 99 and RH 2000 as its official reference systems. (Lantmäteriet, 2018e) The systems are implemented in more and more municipals, authorities and organisations.

5.2 GNSS systems

The term GNSS, Global Navigation Satellite Systems, is a umbrella term for several satellite navigation and positioning systems, for example the American Global Positioning System , the

Russian Global Navigation Satellite System, and the European Galileo system (Lantmäteriet et al., 2013). Satellite positioning is a system in which satellites are used as reference points to provide autonomous geospatial positioning (Walker & Awange, 2018). The satellite system can be described as an active dynamic reference system where the satellites transmit signals with information about its time, position, and status (Lantmäteriet, 2017).

5.2.1 Global positioning system – GPS

The American Global Positioning System, GPS, was the first GNSS system and it became fully operational in year 1995 (Walker & Awange, 2018). The system is administered and developed by the United States and was initially developed for military usage (Granhage, 2011; Walker & Awange, 2018).

The system consists of three segments; the space segment, control segment and user segment. (National Coordination Office, 2017b) The space segment usually consists of 24 operational GPS satellites, evenly arranged into six orbital planes distanced around 20,000 kilometres above earth's surface. The control segment is a global network of control stations that track and monitor the satellites, regulate their orbits and the information send out in the signals (National Coordination Office, 2017a). The third segment, the user segment consist of all GPS receivers that can collect and use the information in the satellite signals, for example surveying equipment (Lantmäteriet et al., 2013).

5.2.2 The Russian Global Navigation Satellite System – Glonass

The Russian Global Navigation Satellite System, Glonass, was similar to the GPS system initially intended for military usage. (Lantmäteriet, 2018c) The system is administered and owned by the Russian military and has been fully operational since year 1999 for civilian usage.

Under ordinary circumstances, the system have 24 GPS satellites in operation, evenly divided over three orbital planes which are located around 19,000 kilometres above earth's surface. (Lantmäteriet, 2018c) The satellite orbits have a higher inclination compared to the equatorial plane than those in the GPS system which means that the satellites turn at a higher altitude. This result in that the system has a better coverage at northern latitudes than the GPS system. The Glonass satellites are controlled by control stations which are located mainly in Russia.

5.2.3 European Union's Satellite Navigation System - Galileo

Galileo is the European Union's Satellite Navigation System that is planned to be in operation by 2020. (European GNSS Agency, 2016) The system is in difference to the GPS and Glonass systems under civil control and a joint initiative by European Commission, the European GNSS Agency and the European Space Agency. The development of Galileo started in the end of 1990 and in 2016 had 18 of the planned 30 satellites been launched into space. The satellites are evenly distributed between three orbital planes, distanced around 23,000 kilometres from earth's surface and the satellites will have a higher inclination than the GPS system. (European Space Agency, 2018) The system is designed to be fully compatible with the GPS and Glonass systems.

6 Detailed Surveying

Detailed surveying includes measuring in and setting out, which traditionally has been the mainly tasks of a surveyor (Granhage, 2011; Peab, 2018). Measuring in is the process of measuring points in the terrain, and interpret the position to coordinates (Lantmäteriet, 2015). Sometimes does it also include to transfer the measured data to a drawing or map (Granhage, 2011). Measure in can be performed before a construction project, or after a construction has been completed (Uren & Price, 2010).The surveys before a construction project start are performed to have the correct data for planning and designing the construction while the surveys performed afterwards are done to know how the correct position of the construction elements, since changes might have been made during the construction process. Moreover, setting out is the process of transferring points or lines on a map or drawing to the real terrain. The points or lines are marked in the terrain with for example pegs, or spray-paint (Granhage, 2011; Uren & Price, 2010). The workers and machine operators then use these markers as guidance to perform construction tasks such as excavations or pipe-laying.

As previously mentioned in chapter 5 can surveying be divided into terrestrial surveying, measurements on the surface of earth, and GNSS surveying, measurements performed with satellites (Lantmäteriet et al., 2013). This chapter will focus on GNSS surveying, since it is the most common form of detailed surveying today. However, an introduction will be given about terrestrial surveying, since surveying originate in terrestrial measurements and are needed when GNSS measurements cannot be performed (Lantmäteriet et al., 2013).

6.1 Terrestrial measurements

Terrestrial surveying refers to field measurements carried out on or near the surface of earth with equipment located at earth's surface (Lantmäteriet et al., 2013). Terrestrial surveying was previously used for both control surveys and detailed surveys. Today is it mainly used for detailed surveying with the exception of height measurement when establishing a control network for heights (Lantmäteriet, 2015).

Terrestrial surveys involve measurements of distances and angles. Distance measurements are linear measurements that can be divided into horizontal distances, vertical distances and slope distances. (Walker & Awange, 2018) Angle measurements can be either vertical angles or horizontal angles. The vertical angle is used to obtain the elevation of points and to convert slope distances to horizontal distances. Horizontal angels are mainly used to obtain directions to control points or points to set out.

Distance measurement can be performed with tape or more commonly an electronic distance meter, EDM and angle measurements can be performed with a so called theodolite (Lantmäteriet et al., 2013; Schofield & Breach, 2007). Today are these measurements performed in one single measurement using a total station (Lantmäteriet et al., 2013). Angle and distance measurement are the only measurements needed to determine the horizontal and vertical position of a point. The vertical distance can also be determined using levelling with either a level or laser equipment (Lantmäteriet, 2015).

6.1.1 Operation process for terrestrial measurements

Before detailed measurements can be performed is planning of the survey needed so the client requirements, existing geodetic infrastructure and other fundamental aspects, important for the survey are known (Lantmäteriet, 2017b). Based on the requirements and existing geodetic infrastructure can the method and instrumentation for a terrestrial survey be chosen. (Lantmäteriet, 2015) Furthermore, the planning involves choice of documentation type, if marking should be used and to what extent self-monitoring should be applied. When the planning is performed the next step is to establish the measuring station, so the equipment's position and orientation is known. (Lantmäteriet, 2017b) This is a crucial part of surveying since an error in the establishment will affect the upcoming detail measurements in field. Therefore, the establishment is followed by a control in which it is investigated that the correct control points have been used, that the markings are intact and that the specified coordinates are correct.

When the planning, station establishment and control have been performed can the detailed surveying with field measurements take place (Lantmäteriet, 2017b). During measuring in is data collected which might need processing depending on method and the equipment used. (Lantmäteriet et al., 2013) The processing transforms the measure data to coordinates which in turn might be used for production of maps or drawings. Moreover, when setting out will data about the points' location be loaded into the equipment and be used to locate the points. The points will then be marked and possibly also controlled. The control is performed in the same way as measuring in and the data collected can be used as control data.
In a simple way can the processes of terrestrial detailed surveying illustrated as shown in Table 1.

Table 1. Schematic table of the operation process when performing terrestrial measurements. Author´s own copyright

Planning	Station Establishment	Control	Measurements and self-monitoring	Data processing
Measure in				
• Client requirements, tolerances, etc. • Available geodetic infrastructure • Choice of method and equipment • Documentation type	• Specify the position and orientation of the equipment	• Control of the station establishment • Correct control points are used • Specified coordinates are correct	• Collect measurement data • Self-monitoring	• Calculate coordinates • Mapping – produce map or drawing from the measurements
Setting out				
• Client requirements, tolerances, etc. • Available geodetic infrastructure • Choice of method and equipment • Type of markings • Comply coordinates for setting out	• Position and orientation of the equipment	• Control of the station establishment • Correct control points are used • Specified coordinates are correct	• Set out pegs, lines and levels • Self-monitoring	• Coordinate calculations of control data

6.1.2 Instruments for terrestrial measurements

Several measurement techniques and equipment can be used for measurement of distances, angels, and heights. Depending on the requirements from the client, stated in the project documents, and the available geodetic infrastructure will the most suitable technique and equipment be chosen. The most common instruments for terrestrial surveying are presented in the following section.

6.1.2.1 Distance Measurements: EDM- instruments

For measuring of distances can an electronic distance meter be used which is a measurement technique using radio waves, light waves or infrared light (Breach, 2014). The technique is used in total stations, hand held distance meters, and laser scanners (Walker & Awange, 2018). EDM instruments are based on the principle that a radio wave, or light wave is sent from the EDM instrument towards a retroreflector or a target point and is then reflected to the EDM device. (Granhage, 2011) The distance can be calculated since the time for sending and receiving the signal it is known as well as the speed of light. The speed of light is however affected by the air temperature and air pressure, hence do these parameters need to be measured and entered to the EDM device when performing high accuracy measurements.

Today, modern EDM devices use infrared light and have capability of measuring distances up to around 10 kilometres when using retroreflectors (Breach, 2014). The devise exists in different accuracy classes, but a typical accuracy is ± 3 millimetre and additional ± 3 millimetre per kilometre to the target point (Granhage, 2011).

6.1.2.2 Angle measurements: Theodolite

Angle measurements can be performed with an instrument called theodolite, which can be either optical or electronic (Uren & Price, 2010). Angle measurements with theodolites are performed in two planes; horizontal and vertical. (Granhage, 2011) The instrument can be adjusted in horizontal and vertical directions and has binoculars to assist in targeting the instrument. The angles are determined by first directing the instrument towards one point, and if a manual instrument is used the angle is read manually and noted, then the instrument is directed towards another point and the angle is noted. For optical instrument can then the angle between the two points then be calculated manually. For electronic instruments will the angle be calculated and displayed automatically (Uren & Price, 2010). Today is mainly electronic theodolites used (Breach, 2014).

6.1.2.3 Levelling equipment: Level

For determination of elevation or difference in elevation is a process called levelling used. (Walker & Awange, 2018) Levelling can be performed with a level, using differential levelling which is described in this section, or a total station described in chapter 6.1.2.4

Differential levelling heights refer to heights over/under the geoid and throughout time have four types of levels existed: optical-, automatic-, electronic- and laser levels. (Breach, 2014) The level equipment consists of a tripod on which a telescope is mounted, and a separate levelling beam. Today are mainly electronic levels used and the procedure for determining heights with an electronic level is as following; initially the level automatically uses a pendulum device, called compensator for relating the direction of gravity. The operator then has to direct the instrument towards the separate levelling beam, which then can be read by the level instrument itself and the height is automatically displayed.

Another common levelling instrument is laser levels that use a rotating head to project a laser beam in a plane perpendicular to the direction of gravity. (Breach, 2014; Lantmäteriet et al., 2013) A levelling beam or portable sensor that detect the laser beam can then be moved around on the construction site to note heights.

6.1.2.4 Combined measurements of distances and angles: Total station

Today is the total station the standard instrument for terrestrial detail surveys, and a total station is shown in Figure 4 (Lantmäteriet et al., 2013). The instrument consists of a built in electronic distance meter, a theodolite and a data unit for collection and processing of data as well as a separate retroreflector with a remote control to operate the total station at a distance (Breach, 2014). A total station can measure horizontal-, and vertical angels, and vertical-, horizontal- and slope distances. (Lantmäteriet et al., 2013) A position is determined through trigonometric calculations of the data. The instrument allows for determination of points position through single measurements.

Figure 4. Total station on tripod. Frank C. Müller). CC-BY-SA-4.0

Distance measurement can be performed in several ways depending on the total station and the measurement uncertainty is therefore depending on which total station is used. (Granhage, 2011) When performing high accuracy distance measurements will the measurements be performed five times and the average distance will be given. The measurement uncertainty of this type of distance measurement is on millimetre level. Simple measurements only measure the distance once and the measurement uncertainty is on centimetre level. For example, Topcons robotic total station, GT-500 has an accuracy of ± 2 millimetre ± 2ppm (Topcon, 2016).

A total station can also be used for determination of heights or difference in heights using trigonometric levelling. (Walker & Awange, 2018) By measuring the vertical angle and slope distance to the target point can the height be calculated using trigonometry.

6.1.3 Sources of errors and limitations in terrestrial measurements

When performing surveying, no measurements are ever certain and therefore is the accuracy, or measurement uncertainty of interest. (Schofield & Breach, 2007) Accuracy is a measure of reliability and the accuracy of terrestrial measurements are due to several factors and errors that can affect the measurements (Lantmäteriet, 2017b). The main factors and sources of errors are natural errors caused by for example the weather, instrumental errors caused by the imperfections in the geodetic infrastructure or the surveying equipment, and human errors, caused by the operator of the equipment (Schofield & Breach, 2007). Several different factors and sources of errors are listed below:

Natural errors or limitations:

- Meteorological variations. For example, the air temperature and air pressure affect the speed of light, which in turn affect the distance measurements (Granhage, 2011). Wind causing vibrations or movements in the equipment can also cause errors in the measurements (Schofield & Breach, 2007).
- Landscape and vegetation. The sight to the measured object might be disturbed by the landscape, buildings, or vegetation (Schofield & Breach, 2007).
- Ground conditions. Settlements of the equipment will cause errors in the readings (Schofield & Breach, 2007).
- Ground movement. (B. Larsson, West Link project presentation, March 19, 2018) During long projects might the reference systems position or the ground on which a project is constructed on change due to ground movement from for example land uplift or settlements. However, new active reference systems will monitor these changes and the movements are often considered.

Instrumental errors or limitations:

- The method for performing station establishment. Establishment through GNSS-measured starting points gives lower absolute position uncertainty than station establishment from the main network. (Lantmäteriet, 2017b).
- The quality or accuracy of the reference points or reference network. The accuracy of a measurement can never be better than the accuracy of the reference systems used (Lantmäteriet, 2017b).
- The number of reference points used when performing station establishment. Generally, will the measurements be more accurate when using several, well distributed reference points for station establishment (Lantmäteriet, 2017b).
- The specified measurement uncertainty for the measurement instrument. All measurement instruments have an uncertainty to its measurements (Lantmäteriet, 2017b).
- The condition of the measuring equipment (Lantmäteriet, 2017b). The instruments should be calibrated and in good condition to reduce the risk of measurement errors.

Human errors or limitations:

- Incorrect usage of the equipment.
- The usage of over determination. When performing several measurements for the same measurement can large errors in the measurement procedure can be detected. It will also reduce the uncertainty in the reading (Lantmäteriet, 2017b).
- Observing and booking errors (Walker & Awange, 2018). However, more and more equipment is automated, and hence will these mistakes and errors be avoided.

- Processing of measurement data. When calculating coordinates, distances, angles etc from measurement data will mathematical formulas of different quality be used. Some are rigorous, and others are approximate which will add errors to the measurements (Schofield & Breach, 2007).

6.2 GNSS measurements

GNSS measurements are based on measurements from satellite signals and the measurements are related to the reference ellipsoid, a mathematical model of earth, which was presented in chapter 5.1 *Geodetic Infrastructure* (Schofield & Breach, 2007). Satellites used for GNSS positioning are situated in pre-determined orbits around earth and send out signals with information regarding their exact position and the time for sending the signal (Granhage, 2011). When performing GNSS positioning are GNSS receivers used to collect the satellite signals and also send out signals at the same time as the satellite signals (Lantmäteriet et al., 2013; Walker & Awange, 2018). For the satellite signals to be transferred and received by the GNSS receiver is a good view of the sky required (Schofield & Breach, 2007) Tall buildings or vegetation might block the view and prevent GNSS measurements to be performed.

When using GNSS systems for measuring in can two systems be used; code measurement or /and carrier phase measurements (Granhage, 2011; Lantmäteriet et al., 2013). When performing code measurements, the GNSS receiver collect and compare the received satellites signals with the signals sent out and calculates the time difference. (Lantmäteriet et al., 2013; Walker & Awange, 2018) The time difference is then used to calculate the receivers distance to the satellite by knowing the speed of light. By using signals from four satellites can the receivers position in three dimensions be determined (Lantmäteriet et al., 2013).

Today is the most common GNSS positioning technique carrier phase measurements which is more complicated than code measurements (Lantmäteriet et al., 2013). The aim of carrier phase measurements is to determine the number of wave lengths, whole number of periods and portion of period, between the GNSS satellite and GNSS receiver. It is difficult to measure the correct amount of whole wave lengths and therefore are measurements often performed in combination with code measurements, and several times at different frequencies to minimise the risk of errors in the measurement. (Lantmäteriet, 2018a) In addition, it is often performed as relative positioning, which is described in chapter 6.2.2. Theoretically, carrier phase measurement can be performed with an accuracy of around two millimetres.

6.2.1 Absolute positioning

With absolute positioning is a GNSS receiver's position determined entirely by using satellites. (Granhage, 2011) Only one GNSS receiver is used to calculate its distance to satellites. A schematic figure of absolute positioning is shown in Figure 5. The measurement uncertainty of the positioning is from a couple of meter to 10 meters; hence the method is not recommended for geodetic measurements and rarely used for surveying in the construction industry (Lantmäteriet, 2017d).

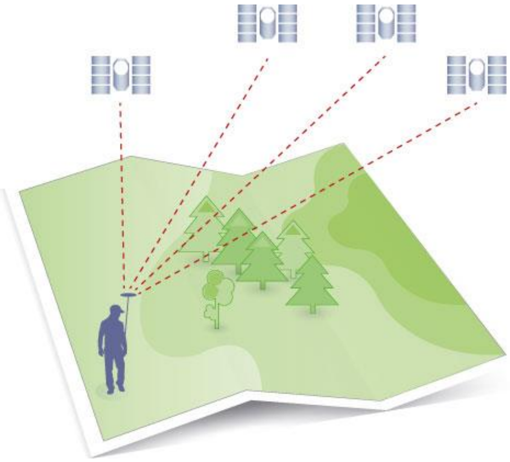

Figure 5. Schematic figure of absolute positioning (©Lantmäteriet, 2018) Reprinted with permission

6.2.2 Relative positioning

Surveying in the construction industry is mainly performed with relative positioning which means that a position is measured relative to another known position (Granhage, 2011). Relative measurements require two or more GNSS receivers to simultaneously collect and calculate their distance to the same satellites (Lantmäteriet et al., 2013). Signals from four to five GNSS satellites are required (Granhage, 2011). A schematic figure of relative positioning is shown in Figure 6 below.

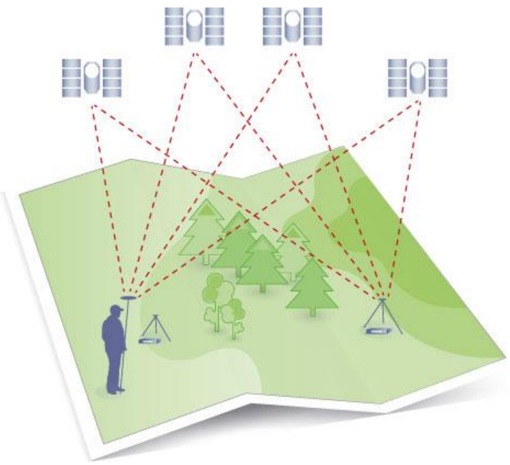

Figure 6. Schematic figure of relative positioning (©Lantmäteriet, 2018) Reprinted with permission

The known position is realised by using either a fixed reference point, for example a SWEPOS station or by using a base station if the distance to a fixed reference station is too long. (Granhage, 2011) A base station is a temporary GNSS receiver that is positioned over a known point. Since the position of the fixed reference point or base station is known, the error in the measurements can be calculated. Knowing the measurement error from the satellites, positioning with the portable GNSS receiver can be performed more accurately. The measurement uncertainty of relative positioning is on centimetre level (Lantmäteriet, 2017d).

The most common methods for relative measurements are Differential GNSS, Real time kinematics, Network real time kinematics and static measurements (Granhage, 2011).

6.2.2.1 Differential GNSS

Differential GNSS is an umbrella term for code measurements with several GNSS receivers (Lantmäteriet, 2018b). The principle for differential measurements is that a GNSS receiver is placed at a known position and another portable GNSS receiver is moved around to points that needs to be measured in or set out. (Lantmäteriet et al., 2013) The measurements are performed in real-time and the coordinates for the portable GNSS receiver is calculated after every measurement. To increase the efficiency and accuracy can several stationary GNSS receivers or portable GNSS receivers be used. The measurement uncertainty for DGNSS is less than one meter.

6.2.2.2 Real time kinematics

Real time kinematics, RTK, is operated in the same way as differential GNSS; a reference station, or a GNSS receiver placed at a known position, is used together with a portable GNSS receiver. The portable GNSS receiver is moved around to points that need to be measured in or set out and the measurements are performed in real-time. (Lantmäteriet et al., 2013). The difference between the methods is that real time kinematics uses both code measurements and carrier phase measurements, comparted to DGNSS that only uses code measurements. The measurement uncertainty is around one centimetre at good conditions, but long distances to the fixed reference station (>15 km), and large and fast changes in the ionosphere or troposphere can increase the uncertainties (Lantmäteriet, 2018h).

6.2.2.3 Network real time kinematics

Network real time kinematics, is a development of the simpler system RTK and uses two or more reference stations (Lantmäteriet, 2018h). The reference stations continually send their measurements to an operational centre which collects the data and sources of errors caused by disturbances in the atmosphere, and errors in time measurements. The users can access the information through a network RTK service which provides the users with information regarding measurement corrections. Today is a virtual reference station the most used network RTK method. Data about measurement corrections is transferred to the portable GNSS receiver through a virtual reference station that is simulated by the operational centre.

By using network RTK can measurement errors due to the atmosphere be eliminated (Lantmäteriet, 2018f). The measurement uncertainty of network RTK is dependent on the distance between the reference stations in the active reference network. (Lantmäteriet, 2017c) The original active network had a distance of 70 kilometres between the stations but since 2010 has a condensation of the network been performed. Today, the network has stations distances down to 35 kilometres or 10 kilometres in limited areas. The measurement uncertainty of network RTK measurements relative to the net density and the distance between the measuring point and nearest reference station can be seen in Table 2.

Table 2. Measurement uncertainty of network RTK measurements relative to net density and distance to nearest reference station. (Lantmäteriet, 2017c)

Station distances - 70 kilometres			
Distance to nearest station	< 10 km	10-20 km	20-40 km
Determination in plan [m]	0.012	0.015	0.018
Determination in height [m]	0.022	0.026	0.030
Station distances - 35 kilometres			
Distance to nearest station	< 5 km	5-10 km	10-20 km
Determination in plan [m]	0.008	0.009	0.010
Determination in height [m]	0.014	0.016	0.018
Station distances - 10 kilometres			
Distance to nearest station	< 2 km	2-3 km	3-6 km
Determination in plan [m]	0.005	0.006	0.007
Determination in height [m]	0.008	0.009	0.010

Currently does southern Sweden, and the main cities along the northern coast have a densified SWEPOS network with a station distance of 35 kilometres. Some areas in Stockholm and Gothenburg have a net density of 10 kilometres. In Figure 7 is the current status on the net illustrated.

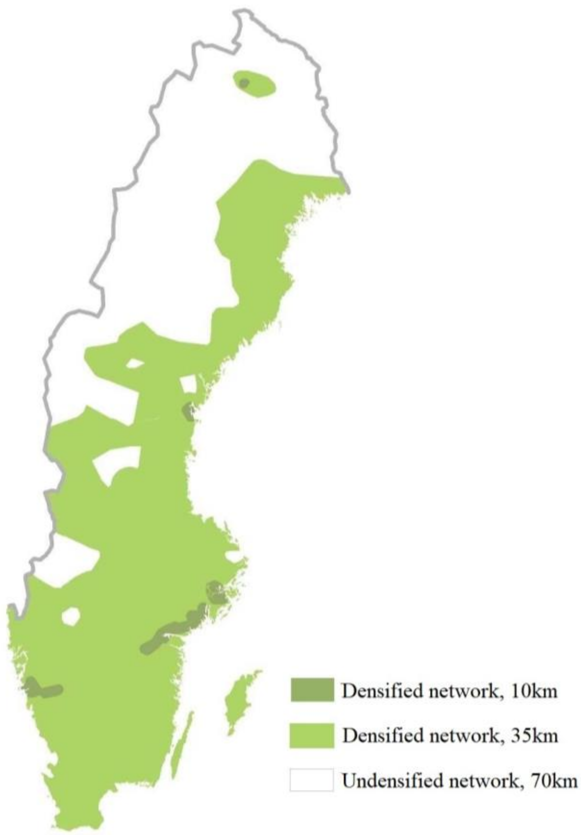

Figure 7. Illustration of the current densification of the SWEPOS network in Sweden. (Swepos, 2018) Reprinted with permission

6.2.2.4 *Relative static measurements*

The method relative static measurement means that a position is determined with calculations after the measurements are done (Granhage, 2011). The measurements are performed as both code and carrier phase measurements with two or more GNSS receivers that collect satellite signals from all available GNSS satellites (Lantmäteriet et al., 2013). The time of measurements can be in the range from minutes up to one day (Granhage, 2011). The measurement uncertainty is dependent on the distance to the reference stations, number of GNSS satellites, strength of signal, signal interruptions and changes in the atmosphere (Lantmäteriet et al., 2013). Static measurements with long observation times and after calculations are often the most accurate positioning method since more reliable data to the satellites orbits and other sources of errors for example in the atmosphere and ionosphere can be assessed (Lantmäteriet, 2018i). The measurement uncertainty is around 0.5 to 2 centimetres (Granhage, 2011).

The GNSS receivers need to collect signals from the same satellites which might be hard in areas with heavy vegetation or high buildings (Lantmäteriet et al., 2013). Therefore, it is sometimes important to plan static measurements in advance to know how many satellites that will be visible.

6.2.3 Operation process for GNSS measurements

Detailed surveying require planning before measurements can take place (Lantmäteriet, 2017b). When performing GNSS based detailed measurements is the process the same with planning, station establishment, control, field measurement, self-monitoring, and data processing. However, the planning covers some other aspects and the station establishment and field measurements will be performed in different ways.

When planning for a GNSS based survey does not only the client requirements, available geodetic infrastructure, documentation type, markings, and self-monitoring need to be considered. Since the local environment where the survey will be performed might restrain the work, it is important to take it into consideration. Buildings and vegetation might cover the GNSS receivers sight to the satellites, the amount of satellites might be too few for accurate positioning or the satellite geometry is not acceptable (Lantmäteriet, 2017c).

The station establishment is performed to know the equipment’s position and orientation. (Lantmäteriet, 2017b) With GNSS based technologies can this be done through satellite positioning instead of using a fixed reference network with reference points. As described before is the station establishment a crucial part of surveying and is therefore followed by a control.

Prior the field measurements are the equipment’s functionally and configuration checked and this can be performed trough measurement of control points (Lantmäteriet, 2017c). When performing GNSS surveying are the atmosphere and ionosphere conditions of interest since they might affect the accuracy of the measurements (Lantmäteriet, 2017c). Therefore, are the atmosphere conditions noted before or during the measurements. Self-monitoring is performed before, during or after the measurements take place. As described in chapter 6.1.1 does some measurement methods require data processing after the measurements are performed. The whole operation process is schematically illustrated in Table 3.

Table 3. Schematic table of the operation process when performing GNSS measurements. Author´s own copyright.

Planning	Station Establishment	Control	Measurements and self-monitoring	Data processing
Measure in				
• Client requirements, tolerances, etc. • Available geodetic infrastructure • Local environment at the construction site • Satellite coverage • Choice of method and equipment • Documentation type	• Specify the position and orientation of the equipment	• Control of the station establishment • Correct control points are used • Specified coordinates are correct • Control of equipment • Control of atmosphere conditions	• Collect measurement data • Self-monitoring • Control of atmosphere conditions	• Calculate coordinates • Mapping – produce map or drawing from the measurements
Setting out				
• Client requirements, tolerances, etc. • Available geodetic infrastructure • Local environment at the construction site • Satellite coverage • Choice of method and equipment • Type of markings	• Position and orientation of the equipment	• Control of the station establishment • Correct control points are used • Specified coordinates are correct • Control of equipment • Control of atmosphere conditions	• Set out pegs, lines and levels • Self-monitoring • Control of atmosphere conditions	• Coordinate calculations of control data

6.2.4 Instruments for GNSS measurements – GNSS receivers

To perform GNSS surveying a GNSS receiver is needed which can collect GNSS satellite signals and also send signals, similar to those sent from the satellites (Lantmäteriet et al., 2013). Simplified is the GNSS receivers function to receive the satellite signal trough the antenna and then convert the signal to a lower frequency and compare it to the signal generated in the receiver. This is performed to determine the distance to the satellite sending the signal. Most receivers are equipped with a processing device for calculation of position, velocity and clock errors.

Several GNSS receivers of varying quality exist and for surveying is the choice of receiver dependent on the type of survey performed and the accuracy needed (Schofield & Breach, 2007). For example, for high accuracy relative positioning is a GNSS receiver capable of carrier phase measurements needed. Most modern receivers can track all visible satellites simultaneously, regardless of GNSS system (Schofield & Breach, 2007). The receivers can be either hand-held, or mountable on for example construction vehicles (Walker & Awange, 2018). For example, the accuracy of Leica iCON gps 80 is 8 millimetre + 1ppm in the horizontal direction and 15 millimetres + 1ppm in the vertical direction (Leica Geosystems AG, n.d.).

6.2.5 Sources of errors and limitations for GNSS measurements

In addition to the factors and sources of errors listed in chapter 6.1.3 are the accuracy of GNSS surveying also affected by other factors. These factors can be divided into three categories; satellite related errors, transfer errors, and satellite receiver errors (Lantmäteriet et al., 2013):

Satellite related errors or limitations:

- Satellite constellation or satellite geometry. Too few or bad geometric distribution of the satellites are causing errors or uncertainties in the measurements (Walker & Awange, 2018). To assure good accuracy of the measurements are five satellites with high geometric spread needed (Lantmäteriet, 2017c)
- Orbital errors or ephemeris errors. Errors caused by disturbances in the satellite orbits caused by external forces such as solar and lunar gravitational attraction (Walker & Awange, 2018).

Signal transfer errors or limitations:

- Multipath errors. Multipath errors occur when the satellite signal do not travel direct from the satellite to the receiver but is reflected on a nearby surface such as a building or the ground (Schofield & Breach, 2007).

Receiver errors or limitations:

- Errors related to the measurement method. (Lantmäteriet et al., 2013) The accuracy of a code measurement are around 30 centimetres and around 2 millimetres for carrier phase measurements.
- Data communication errors. Errors due to lacking or poor service (Lantmäteriet, 2017c).
- Electromagnetic errors. Errors caused by disturbance from a power-line, cell tower, radars etc.
- Clock errors. Errors in the satellite or receiver clock so the distance calculations are based on wrong in-data. Satellites have atomic clocks and the satellite receivers use precise clocks due to costs. This as well as that the clocks must be synchronized are a subject for errors (Walker & Awange, 2018). Clock errors are eliminated through relative measurements (Lantmäteriet et al., 2013).
- Errors due to the GNSS receiver's antenna. When measuring in, the estimations refer to the position of the electric centre of the GNSS receiver's antenna. The electric centre is a virtual point whose location differ from the geometrical centre of the antenna. The difference between the centres depends on the inclination of the satellite signal and the quality of the GNSS receiver. For advanced antennas is this difference on millimetre level and for simple antennas on centimetre level (Lantmäteriet et al., 2013).

7 Machine control systems

During recent years have machine systems been developed where the surveying tools are implemented into the construction machines and surveying can be performed simultaneously as the construction machines are operated (Schofield & Breach, 2007). These systems are called machine control systems or machine guidance systems and can be implemented in excavators, graders, loaders etc. (Granhage, 2011; Schofield & Breach, 2007) Machine control systems are systems where information from a drawing or model and information from monitoring devises on the machines are used to directly control the machine's hydraulics, to automate for example the blade of an excavator. Machine guidance is in difference when the system is guiding the operator through a screen, with either lights or arrows, so the operator can move the blade or excavator to the correct position. This chapter will focus on machine guidance for excavators.

Machine guidance systems consist of a positioning system and a control system consisting of sensors and a control box (Leica Geosystems AG, 2014). The positioning system can be controlled by laser, GNSS or a total station. (Granhage, 2011; Trimble, 2014) The sensors on the machine are connected to the control box and provides the control box with information. The control box process data from the monitoring devises as well as information from files or terrain models and guide the operator to the desired position. The operator is guided through a screen where the files or models are shown in plan and cross-section. (E. Hjertberg personal communication, March 2, 2018) The system then indicates trough lights or arrows if the operator should move the blade in the vertical or horizontal direction

Machine guidance systems are said to save time and costs during constructions if used correctly (Nohlen & Petschek, 2014). The manual surveying with markings can be reduced and hence is the safety on the construction site increased due to less opportunities for potentially dangerous machine – ground worker interactions (Samuel A berg, 2011; Schofield & Breach, 2007). Updates of the construction drawings are also relatively easy to implement since they only need to be transferred to the systems control box. (Schofield & Breach, 2007) Additionally, the systems can warn for dangers at the construction site when the machine gets too close to for example pipes or contaminated land. Furthermore, the systems can be used for data collection that can be used for daily progress updates and calculations for the amount of excavation, pipe laying etc. that have been done. This can then be used as a base for invoicing documentation or for tender calculations.

Since the system minimize the need of manual surveying is the surveyors' role changed and their main task is to set up the systems needed for the operation, assure that the correct coordinate systems are used and that the drawing or model are correct and working (Schofield & Breach, 2007). The surveyor can also assist the operator when a problem related to measuring in or setting out is encountered. This can be done digitally without the surveyor having to visit the site.

Since the systems guide the machine operator based on the drawings or models in the control box is the accuracy of the data in them of great importance. (Nohlen & Petschek, 2014) Each calculation error in the data is immediately affecting the construction and hence is the planner's responsibility increased.

7.1 Data to machine guidance system

When using machine guidance systems are several different files needed for different tasks, for example files with instructions to the system, files with the used coordinate system, reference files over the objects to be built, and helpfiles for background images (E. Hjertberg, personal communication, April 17, 2018). The file with instructions to the system allows a surveyor to access the machines control box for remote support. The file with the coordinate system is needed for guiding the operator to the correct position and saving the performed measurements in the correct coordinate format. The reference files are files that illustrate different construction objects and can be point files, line work files or terrain models. The different types of reference files will be presented below. Helpfiles are used as background images on the where specific objects are not given specific plan or height coordinates. The files are instead used as background files and the operator will not be guided in plan or height, the operator can only check its position through the visualisation on the screen.

7.1.1 Reference files

The reference files can be produced by the project planner direct if the client of a project has order it, or by a surveyor if no such files exist and a contractor want to work with machine guidance. (D. Gullberg, personal communication, March 28, 2018) If the files are created by someone else than the project planner will the drawings for the project be used as the base for the files or models.

7.1.2 Point files

Point files are files where the content is illustrated trough points. (E. Hjertberg, personal communication, April 17, 2018) This type of file can be used for illustrating control points that the machine operator can measure against to calibrate the system or see that the systems calibration is good enough. Moreover, point files are also good for illustrating street inlets. The points can be given heights, and hence can the street inlets water head be illustrated. The operator can select two wells and the gradient of the water head will be told between the two street inlets. It allows the machine operator to excavate for the pipe between the two inlets.

7.1.3 Line work files

Line work files contain two-dimensional line works of for example road lines and cables. The lines are used for visualising purpose, to direct the operator to the correct position. (E. Hjertberg, personal communication, April 17, 2018) These types of files are used for road-, railroad-, and cable works.

7.1.4 Digital terrain models

Machine guidance systems can also use terrain models for guiding the operator. These models are usually called digital terrain models, DTM, (Schofield & Breach, 2007) and are mainly used for large and more complex projects (T. Rydén, personal communication, February 27, 2018).

Complex terrain models, illustrating several details are time consuming to create and hence is often not all objects illustrated in them (D. Gullberg, personal communication, March 28, 2018). It is usual to have models of for example the excavation bottom or finished surface (E. Hjertberg, personal communication, April 17, 2018). It is important to have an agreement on what and how things should be shown in the DTM. (Nohlen & Petschek, 2014) For example. It is important to have an agreement on which elevation to show in the model for instance excavation bottom or finished surface. If the excavation floor is shown, then the machine operator must know the thickness of the macadam to be laid and if the finished surface is shown, the thickness of the for example concrete base and macadam must be known to excavate to the correct depth (E. Hjertberg, personal communication, April 17, 2018).

Pipes can also be illustrated in terrain models but usually is it avoided since it is unnecessary to illustrate the slope ratios since they need to be adjusted to the soil condition. (Nohlen & Petschek, 2014) Instead is often a line-work file or point file used for illustrating a pipe.

Terrain models can also be used for volume calculations by comparing two models. (E. Hjertberg, personal communication, April 17, 2018) For example, a model of an existing surface can be compared with the DTM to investigate the volume for filling and excavation.

7.2 Positioning and guidance systems in excavators

As previously mentioned, the machine guidance system consist of a positioning system and a control system. The positioning system can be controlled by laser, GNSS or a total station (Granhage, 2011). Laser is used for positioning in one dimension, for vertical guidance on for example an embankment construction. (Leica Geosystems AG, 2014) Positioning with GNSS and total station is used for three-dimensional guidance systems where the operator is guided in both the vertical and horizontal position. Three-dimensional systems can be used for measuring in and setting out points by using the excavator bucket.

7.2.1 One- and two-dimensional guidance systems

The one-dimensional machine guidance system is the most basic guidance system (R. Juhlin, personal communication, March 9, 2018). It can guide the operator in the vertical direction and be used for creation of plane surfaces with or without inclination. (Leica Geosystems AG, 2014) The one-dimensional system consists of the control box, and three sensors mounted on the excavator's boom, stick and bucket. A schematic figure of the sensors position on the excavator is shown in Figure 8.

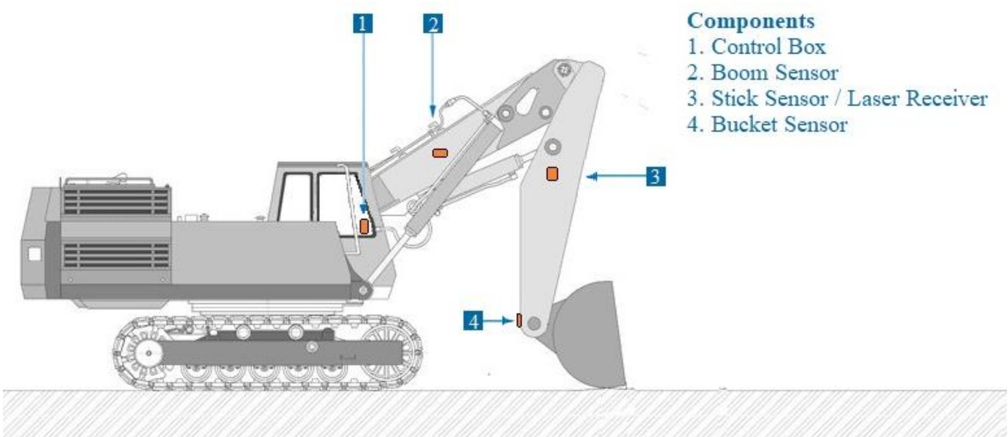

Figure 8. Schematic figure of the components in a one-dimensional machine guidance system. (Edited by author, derived from Igorevich, 2009) Adapted with permission.

The sensor on the stick has a built-in laser receiver which can be used for resetting the system otherwise can a physically defined reference height, for example a curb stone, be used for resetting the system. (Leica Geosystems AG, 2014) The desired depth and slope or the plane is entered to the control box and arrows on the control box display indicate whether the bucket is in plane, or needs to be lowered, or raised. The system can be used for embankment constructions, pipe laying, and foundations.

The one-dimensional system can be extended to a two-dimensional system by adding an extra sensor to control the machines inclination. Preferably is also a compass added and if the excavators bucket has a tilt function, it is recommended to add a sensor to control the tilt (Leica Geosystems AG, 2014). A two-dimensional system is illustrated in Figure 9. The extra components in the two-dimensional system allows for the excavator to be moved around without losing the direction of the slope. The system is suitable for example road constructions, ditch construction, and pipe-laying (Trimble, 2014).

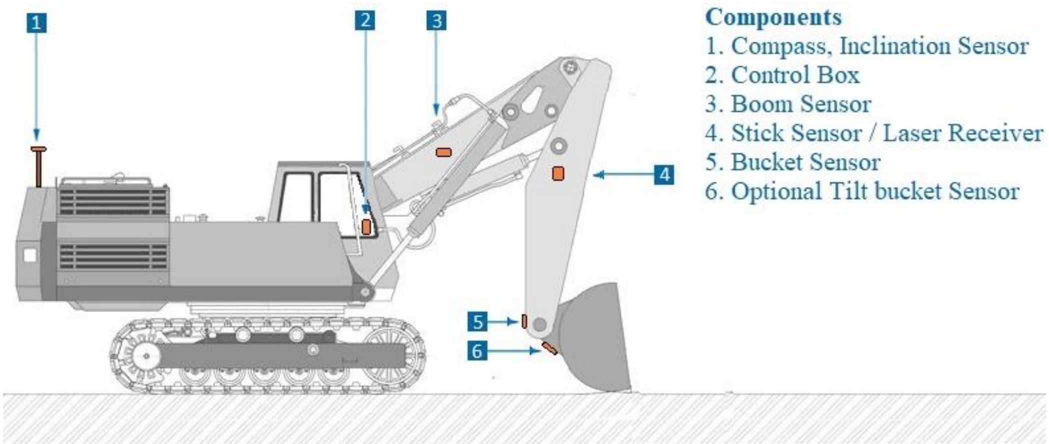

Figure 9. Schematic Figure of the components in a two-dimensional machine guidance system. (Edited by author, derived from Igorevich, 2009) Adapted with permission

7.2.2 Three-dimensional guidance systems with GNSS

Three-dimensional GNSS machine guidance systems can guide the operator in plane and height and be used for measuring in and setting out points by using the excavators bucket. (Leica Geosystems AG, 2014) In addition to the components used in a two-dimensional system does a three-dimensional system also use a high precision GNSS receiver for positioning of the excavator. The system also has a radio antenna to collect signals regarding measurement corrections. The control box contains the terrain model and process the data. The machine system matches the information from the GNSS receiver and sensors with the terrain model to guide the operator to the desired positions or heights (E. Hjertberg, personal communication, March 2, 2018). The components to the system is shown in Figure 10.

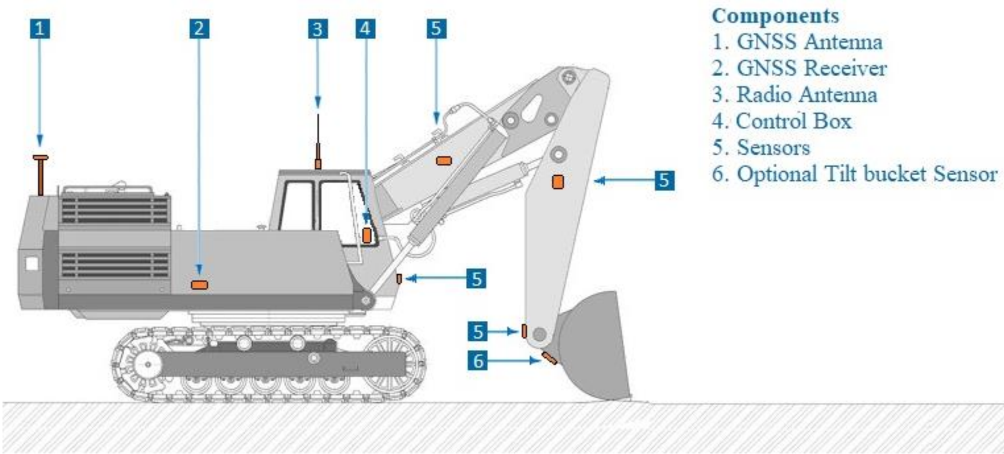

Figure 10. Schematic figure of the components positions in a three-dimensional machine guidance system. (Edited by author, derived from Igorevich, 2009) Adapted with permission

The system can have one or two GNSS receivers. (Trimble, 2014) Compared to the system with one GNSS receiver can the system using two GNSS receivers calculate both the machines position and its direction.

The measurement uncertainty of the GNSS unit in a machine guidance system is ± 20 millimetre and the measurement uncertainty of the sensors is ± 2 millimetres per meter system (R. Juhlin, personal communication, March 9, 2018). The accuracy can be increased by installing a laser receiver. (Trimble, 2014) With a laser receiver, the excavators bucket has a measurement uncertainty of 3 to 6 millimetres in the vertical direction. A better accuracy is also provided with a machine guidance system using total stations.

7.2.3 Three-dimensional guidance systems with total station

Three-dimensional machine guidance with a total station can be used at locations where GNSS positioning is not possible due to no or low satellite coverage (Sitech, 2018a). However, it is not a common method since the total station might be in the way and hence have to be moved during the construction. (T. Rydén, personal communication, February 27, 2018) Still, the system is usually used on projects where a high accuracy is needed, for example on construction of football fields, and construction projects on airfields.

The total station used is a robotic unmanned total station with high speed tracking of excavator (Sitech, 2018b). The total station measures angles and distances and provide the information to excavators control box in real time. The measurement uncertainty of the excavators bucket is 2 to 5 millimetres when using a total station (Trimble, 2014).

7.3 Remote support

Today can the surveyor supporting with the machine guidance system access the control box from the office through a server that receives all data from the machines. (Leica Geosystems AG, 2014; Trimble, 2014) The operator can contact the surveyor whenever there is a problem or a need for guidance and the surveyor can enter the server and the files used for the construction without having to visit the construction site. The surveyor can see the files in the same way as it is shown on the screen on the excavators control box. This allows for fast guidance and help which save time on the construction site and also allows the surveyor to assist several construction projects at the same time.

7.4 Operation process for machine guidance systems

As for detailed surveying, the usage of machine guidance system require planning before the construction can take place (Lantmäteriet, 2017b). However, the planning when using machine guidance systems also consist of what machine guidance system to use, and sometimes also the planning and creation of the digital terrain model. When deciding on system is the type of construction, need of accuracy as well as information regarding the satellite coverage at the site important.

The system is installed and set up by a surveyor before it can be used. (E. Hjertberg, personal communication, April 17, 2018) When the setup is performed, the construction can start, and surveying can be performed simultaneously as the construction progress by the excavator itself. It is important that the operator regularly calibrates the system, for example information on the buckets blade since it will wear (Trimble, 2012).

During construction, the control box can collect data that can be sent over to the surveyor or site manager (Leica Geosystems AG, 2014). The data can then be used for mass calculation, information on progress, etc. and be a base for invoice documentation and tender calculations (E. Hjertberg, personal communication, April 17, 2018). The process when using machine guidance systems is schematically shown in Table 4.

Table 4. Schematic table of the operation process when using machine guidance systems. Author´s own copyright

	Planning	Installation / set up	Control	Measurements	Data processing
Measure in	• Client requirements, tolerances, etc. • Available geodetic infrastructure • Local environment at the construction site • Satellite coverage • Choice of system • Creation of digital terrain model and other in-data to the system	• The system is installed or set up in the machine	• Calibration of the system	• Measurements can be performed simultaneously as the construction progress	• The data can be sent to a surveyor who process the data to drawings
Setting out	• Client requirements, tolerances, etc. • Available geodetic infrastructure • Local environment at the construction site • Satellite coverage • Choice of method and equipment • Type of markings	• The system is installed or set up in the machine	• Calibration of the system	• Measurements can be performed simultaneously as the construction progress	• The data can be sent to a surveyor for mass calculations or for progress updates

7.5 Sources of errors and limitations for guidance systems

Machine guidance systems with laser and total station or GNSS have the same sources of errors and limitations as mentioned in chapter 6.1.3 and 6.2.5 for respectively system. However, additional sources of errors and limitations exist due to the factors mentioned below:

- Machine guidance with a digital terrain model is highly dependent on the information provided in the model. (Nohlen & Petschek, 2014) Each error in the model will have an immediate effect on the construction if the operator does not notice it.
- The site manager might struggle to visualise the project. (Nohlen & Petschek, 2014)
- The field operations are very dependent on the system. More components are needed in the excavator which means that more things might break or malfunction (Machine Guidance, 2018) However, support systems from the manufacturers exist and hence is the problem not a big issue.
- The buckets blade on the excavator will wear due to usage and the system needs to be calibrated once in a while to get accurate position (Trimble, 2012).
- Software updates are needed at a regular basis. (T. Rydén, personal communication, February 27, 2018)

8 Measurements Errors and tolerances

All geodetic measurements are accompanied with measurement errors (Lilje, n.d.). In construction projects are objects positions almost always specified. However, it is accepted that the true positions of objects vary from the given coordinates. The allowed variation is stated as tolerances. Moreover, to be able to choose a method for surveying, the equipment's measurement uncertainty or accuracy must be expressed is terms that can be compared to the tolerances given.

8.1 Measurement errors

There are several terms to express uncertainties or errors in measurements; accuracy, precision and trueness as well as mean deviation, standard deviation and mean value. The definitions of these are as following:

Accuracy: Indicates the measurements spread around the true value. However, in geodetic measurements are the true value of a measurement not known (Lilje, n.d.). See figure 11 for an illustration of the term.

Precision: The measurements variation from the mean value of the measurements, i.e an unknown value (Lilje, n.d.). Also called Standard deviation (Swedish Standards Institute, 2016). See figure 11 for an illustration of the term.

Trueness: The compliance with the measurements mean value and the true value (Lilje, n.d.). See figure 11 for an illustration of the term.

Mean deviation: A term commonly used for expressing the variations from a true value (Swedish Standards Institute, 2016). Accuracy is often expressed as some type of mean deviation (Lilje, n.d.).

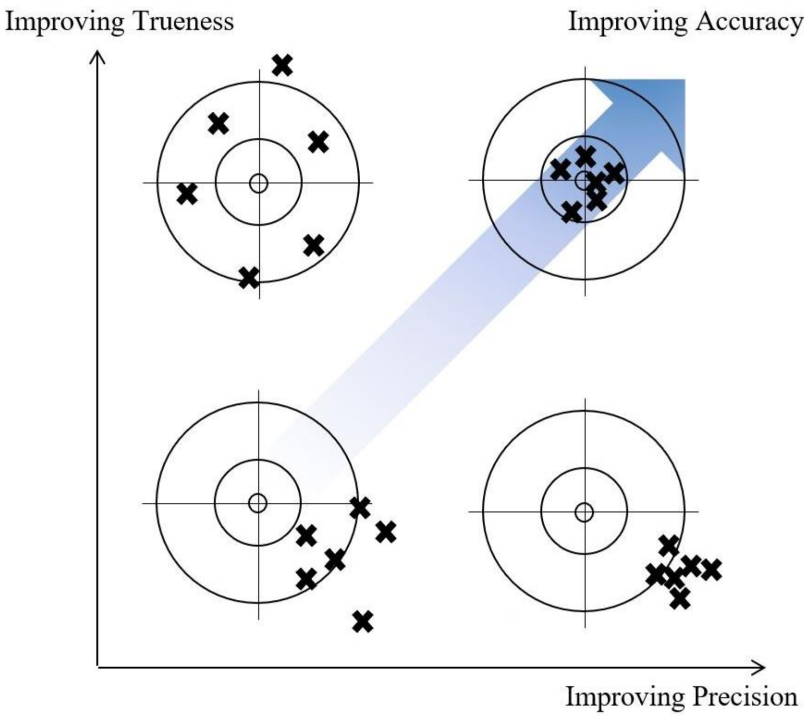

Figure 11. Illustration of accuracy, precision, and trueness. Author's own copywrite

8.2 Construction tolerances

The accuracy needed in the performance of setting out and measure in should always comply with the tolerances set in the construction documents (Byggforskningsrådet, 1998a). The tolerances are often stated in the technical description or drawings, or sometimes it is referred to the Swedish reference book AMA. (Swedish Standards Institute, 2016) If the tolerances are not specified or referred to, the tolerances should be adapted to the objects' technical or functional need.

AMA Anläggning 17 is the current reference book used for preparation and execution of construction works (Svensk Byggtjänst, 2017a). The book is associated with the book *RA Anläggning 17*, which contains advice and instructions related to the reference works given in AMA anläggning 17 (Svensk Byggtjänst, 2017c). In chapter *BJ. Geodetiska Mätningsarbeten*, the geodetic measurements are presented. For tolerances does the book RA Anläggning 17 refer to *the Swedish Standard SIS-TS 21143:2016* and the book *HMK Bygg & Anläggning BA 4 (1998)*.

The Swedish Standard SIS-TS 21143:2016 concerns general requirements as well as requirements for reference systems, reference networks, detail measurements and quality assurance. (Swedish Standards Institute, 2016) Several types of tolerances exist, and the standard defines terms related to construction tolerances:

Tolerance: Within the construction industry, the tolerances are expressed as ± allowed deviation (symmetric tolerance) or with different values of the plus and minus magnitude (asymmetrical tolerance) (Swedish Standards Institute, 2016).

Construction tolerance, T: Refers to the total tolerance for the position of a built component, building or construction. The construction tolerance is comprised of the tolerances for manufacturing, setting out, and assemblage (Swedish Standards Institute, 2016).

Measure in tolerance, T_i: Tolerances when performing measure in (Swedish Standards Institute, 2016).

Setting out tolerances, T_u: Tolerances when performing setting out. The value can either be given or determined from by its statistic relationship with the construction tolerance (Swedish Standards Institute, 2016).

8.2.1 Tolerances for setting out

For tolerances related to setting out does SIS-TS 21143:2016 refer back to AMA Anläggning and the technical description in construction documents (Swedish Standards Institute, 2016).

In the book HMK Bygg & Anläggning BA 4, several examples of construction tolerances have been given for different construction objects, which are presented in Table 5. (Byggforskningsrådet, 1998a) The book refers these construction tolerances as basic tolerances retrieved from AMA and existing construction documents. However, it is stated that the given tolerances might be adjusted to specific cases and that it is important to always check the existing requirements for the specific construction project.

Table 5. Examples of construction tolerances, T, in plan and height for different construction objects. (Byggforskningsrådet, 1998a). (-) indicates that no number was given.

Construction Object		**T in plan [mm]**	**T in height [mm]**
Excavation and foundations	Soil excavation	60-100	50-70
	Rock excavation	60-100	50-70
	Piling	50-100	20
	Ground bed	100	30
Foundations	Base blocks Foundation walls Base plate	20-30	20
Road constructions	Road line in plan	20-50	-
	Road area Clearance Vegetation removal	300	-
	Slopes Breakpoints	100	100
	Subgrade	60	-
	Ditches	100	70
	Subbase	50	-
	Unbound base layer Bound base layer	35	-
	Surface layer	30	-
Pipes and cables	Water pipes Sewage pipes	20-40	10-20
	Electric cable	50	30
	Telephone line	50	20
	District heating pipes	50	20
Earth works	Street	20	10-20
	Green area	20-50	10-50

The construction tolerances, T, for a finished construction object differ from the allowed tolerance when setting out, T_u. The approximative relationship between the two tolerances is according to HMK Bygg & Anläggning BA 4:

$$T_u = \sqrt{k \cdot T^2} \qquad (1)$$

Where k is a constant related to the degree of safety and for normal construction tolerances can k = 0.3-0.4 be chosen. If a higher safety level is desired can k = 0.2-0.3 be chosen.

However, the current Swedish Standard for engineering survey for construction works, SIS-TS 21143:2016, gives another relationship between the construction tolerance, T, and tolerance for setting out, T_u. (Swedish Standards Institute, 2016) The tolerance for setting out is calculated differently for civil engineering works and buildings. Civil engineering works include: bedrock caverns, tunnels, bridges, docks, foundations, railroads, cables and pipes, vegetation areas, road, plan etc. For civil engineering works the following equation is given:

$$T_u = 0.6T \qquad (2)$$

Examples of different tolerances for setting out can be seen in Table 6.

Table 6. Examples of tolerances for setting out, T_u, for civil engineering works. Author's own copywrite.

Construction Object		**T_u in plan [mm]**	**T_u in height [mm]**
Excavation and foundations	Soil excavation	36-60	30-42
	Rock excavation	36-60	30-42
	Piling	30-60	12
	Ground bed	60	18
Foundations	Base blocks Foundation walls Base plate	12-18	12
Road constructions	Road line in plan	12-30	-
	Road area Clearance Vegetation removal	180	-
	Slopes Breakpoints	60	60
	Subgrade	36	-
	Ditches	60	42
	Subbase	30	-
	Unbound base layer Bound base layer	21	-
	Surface layer	18	-
Pipes and cables	Water pipes Sewage pipes	12-24	6-12
	Electric cable	30	18
	Telephone line	30	12
	District heating pipes	30	12
Earth works	Street	12	6-12
	Green area	12-30	6-30

Moreover, the tolerance for setting out, T_u is not an absolute value of the allowed variation in measurements when setting out. (Swedish Standards Institute, 2016) This is instead defined as measurements mean deviation, σ. For normal applications and 95 percent confidence can the allowed mean deviation be calculated as following:

$$\sigma_u = \frac{T_u}{2} \qquad (3)$$

See Table 7 for examples of allowed mean deviations. If a higher level of safety is desired, for example of 99 percent confidence can the mean deviation be determined by dividing T_u with 2.6 (Swedish Standards Institute, 2016).

Table 7. Examples of allowed mean deviations for setting out. Confidence level: 95%. Author´s own copywrite.

Construction Object		**σ_u in plan [mm]**	**σ_u in height [mm]**
Excavation and foundations	Soil excavation	18-30	15-21
	Rock excavation	18-30	15-21
	Piling	15-30	6
	Ground bed	30	9
Foundations	Base blocks Foundation walls Base plate	6-9	6
Road constructions	Road line in plan	6-15	-
	Road area Clearance Vegetation removal	90	-
	Slopes Breakpoints	30	30
	Subgrade	18	-
	Ditches	30	21
	Subbase	15	-
	Unbound base layer Bound base layer	10.5	-
	Surface layer	9	-
Pipes and cables	Water pipes Sewage pipes	6-12	3-6
	Electric cable	15	9
	Telephone line	15	6
	District heating pipes	15	6
Earth works	Street	6	3-6
	Green area	6-15	3-15

8.2.2 Tolerances for measure in

Tolerances for measure in is usually given in a projects constructions documents. (Byggforskningsrådet, 1998a) If no tolerances are given for measure in, does the current Swedish Standard for engineering survey for construction works, SIS-TS 21143:2016 refer to the tolerances given in HMK Bygg & Anläggning BA 3 appendix C. (Swedish Standards Institute, 2016) In addition, the standard state that the maximum measurement uncertainty can be 40 percent of the tolerance for measure in.

The tolerances for measure in given in HMK Bygg & Anläggning BA 3 appendix C applies to when the data is used as in-data in the planning process. (Byggforskningsrådet, 1998b) Furthermore, the book refers to the document HMK-Ge:D, and appendix F. The tolerances given can be seen in table 8. However, HMK.Ge:D, state that the relevant sections of the scripture are found in the new versions: HMK-Geodesi: GNSS-baserad detaljmätning 2015 and HMK Geodesi- Terrester detaljmätning 2015 (Lantmäteriet, 1996). These documents has since the publishing been replaces by newer editions HMK-Geodesi: GNSS-baserad detaljmätning 2017 and HMK Geodesi: Terrester detaljmätning 2017 (Lantmäteriet, 2017b, 2017c). These documents do not mention any tolerances for measure in and hence is the tolerances from HMK.Ge-D. appendix F assumed to be valid.

Table 8. Examples of tolerances for measure in. (Lantmäteriet, 1996)

Construction Object		T_i in plan [mm]	T_i in height [mm]
Buildings	Corner of house	20	-
	Balcony	20	10
	Floor	-	5
	Other objects	20	10
Road constructions	Street Roadway Walkway	30	10
	Ditch Slope	100	30
	Gravel road	50	20
Fence and Poles	Retaining wall	30	15
	Plank fence	30	20
	Fence	50	30
	Poles	50	-
Vegetation and surfaces	Tree	100	30
	Asphalt Concrete slab Stone slab	30	10
	Gravel	50	20
	Grass	100	30
	Other soil surfaces	100	50
Pipes and cables	Street inlets (water and sewage system)	50	10
	Valve or fire hydrant	50	10
	Pipe in open trench	30	15
	Cable in open trench	30	30
	District heating, culvert	30	10
Surfaces (single points)	Natural land	50	50
	Bedrock surface	50	30

As previously mentioned is the maximum allowed measurement uncertainty for measure in 40 percent of the tolerance for measure in (Swedish Standards Institute, 2016). Table 9 show examples of the allowed measurement uncertainties for measure in.

Table 9. Examples of allowed measurement uncertainties for measure in. Author´s own copywrite.

Construction Object		**$T_{i,40}$ in plan [mm]**	**$T_{i,40}$ in height [mm]**
Buildings	Corner of house	8	-
	Balcony	8	4
	Floor	-	2
	Other objects	8	4
Road constructions	Street Roadway Walkway	12	4
	Ditch Slope	40	12
	Gravel road	20	8
Fence and Poles	Retaining wall	12	6
	Plank fence	12	8
	Fence	20	12
	Poles	20	-
Vegetation and surfaces	Tree	40	12
	Asphalt Concrete slab Stone slab	12	4
	Gravel	20	8
	Grass	40	12
	Other soil surfaces	40	20
Pipes and cables	Street inlets (water and sewage system)	20	4
	Valve/ fire hydrant	20	4
	Pipe in open trench	12	6
	Cable in open trench	12	12
	District heating, culvert	12	4
Surfaces (single points)	Natural land	20	20
	Bedrock surface	20	12

9 Results from Interview Study

The following chapter presents the results from the interview study where the following actors have been interviewed:

- Surveyor
- Company developing machine guidance systems
- Project planner
- Site manager
- Operator of an excavator with machine guidance system
- Corporate adviser on insurances

The chapter is structured after the actors interviewed and the focus of the interviews have been to understand the different actor's perspective and thoughts regarding machine guidance and manual surveying. The interviews were performed as semi-structured interviews where a number of questions for each actor formed the base of the interview. The questions are presented in Appendix A. During the interviews were the questions adapted to the knowledge and interest of the interviewee.

The chapter is written as a compilation of the actor's opinions and thoughts expressed during the interview.

9.1 Surveyor

Tobias Rydén (T. Rydén, personal communication, February 27, 2018) started his career as a construction surveyor in 1998. In 2003 he started his own surveying company Trig and today the company have 30 employees and work with surveying, machine guidance, 3D scanning, control measurements, BIM modelling, topographic surveys, etc.

9.1.1 The surveyor's equipment in relation to machine guidance systems

According to Tobias Rydén does surveyors in the construction industry today mainly use relative positioning with GNSS based total stations to perform measurements. The accuracy of the instrument is dependent on for example the location of a project, satellite constellation, and time of measurements but generally is it around +-3 millimetres. One problem with the technique is network shadows where there is no signal for receiving measurement correction data. The surveyors' instrument consists of the total station and a stick, and errors within the equipment itself mainly come from how the stick is tilted. Moreover, the accuracy of machine guidance systems are less accurate since the systems need to have more components to locate the relation to the stick, the angle of the stick, the relation to the boom, and also the location and tilt of the bucket. These extra components result in more sources of errors and hence a less accurate system.

In addition, Rydén has seen that contractors are less interested in updating the systems software's and hence does more sources of errors exist. In contrast, surveyors update their equipment's software whenever a new one is released.

9.1.2 The development of a surveyor's role in construction projects

Tobias Rydén explained in the interview that he five years ago understood and saw that the new technologies and machine guidance systems were here to stay. He chose to see it as an advantage for the company and began to support machine operators with machine guidance models. Today, the company support the construction industry with both machine guidance and with traditional surveying. In addition, he has noted that surveyors today are more focused towards documentation and control measurements than before. Previously were their focus on the construction and had a main task to perform surveying. Today is it however more important with documentation and measure where things are positioned in the end.

9.1.3 Unclear work tasks for surveyors and machine operators

Tobias Rydén state that he is positive to machine guidance systems but adds that it is important that all actors work with what they do best and have the focus on the correct things. A machine operator should be focusing on the production and to excavate. Furthermore, Rydén explain his concerns regarding other actors' thoughts on replacing surveyors with for example a GNSS system. Money is a clear measure for contractors and it is often the reason for trying to cut down the manual surveying tasks in a project. Rydén has hard to accept this reason when construction workers often have to go and buy things during the day since things are missing or the wrong number of things have been ordered. That time waste is not seen as a problem, but the time spent on surveying sometimes is.

Rydén explains his concerns further; a surveyor cost around 600 to 700 SEK per hour and if their work could be performed by anyone, they would not charge that amount per hour. He adds; Is it reasonable that a machine operator that cost 1200 SEK per hour should measure a surface on a project when a surveyor can perform the same task as fast or even faster? Should a machine operator measure and document pipes when its main task is to excavate as fast as possible since other workers will lay pipes afterwards?

There is no list of tasks of what a surveyor or machine operator should do on a construction where machine guidance is used. This have led to a situation where the roles of the two professions are unclear.

9.1.4 The result of unclear work tasks

Rydén explains todays vision when using machine guidance systems; the planners project the construction, then they directly transfer the model to the machine guidance system, the machine operator can then excavate and construct after the model and lastly, the operator can press a button and send the files of how the construction ended up looking. He continues that the vision is good but that the execution of the machine operator limits it. The difference in knowledge and focus between the two professions is the reason for encountering problems when replacing the surveyor with a machine guidance system. Surveyors have been educated in the measurement standards and the requirements the measurements should fulfil. The machine operator does not have this knowledge and additionally has the two professions the focus on different things. The surveyor has the focus towards documentation and the machine operator has the focus on the production. The difference in knowledge, focus and hence interest leads to different result when performing the same task.

Tobias Rydén has seen this difference in result when getting data from a machine guidance system, where a machine operator has performed the measurements. Often does the machine operators not perform the measurements and positioning task in the same way as a surveyor would have, and hence does it become hard for the surveyors to process the data and create for example record drawings from it. In addition, the surveyors are placed in critical situations where they are the ones putting their names on the drawings that should be sent to the client of the project. One example of this is when measureing in existing surfaces. It is important to plan the work to get the shape of the surface correct. Otherwise, if points are missed or wrongly measured might the digital drawing of the surface look very different from reality. If the file later is compared to files of the finished surface and for mass calculations, the result will be different compared to reality.

As previously mentioned did Rydén express his concerns on surveyors being replaced by machine systems and that an excavator probably is not the best alternative for measuring a surface on a project, both due to cost but also errors. An error in a measurement of a surface that later will be used as a reference for mass calculations might lead to loss of income. If a surface is measured in the wrong way might the mass calculations become wrong and the contractor might not be able to charge for the masses that have been lost due to the errors in in-data. In addition, errors in the setting out with machine systems can lead to loss of time due to construction errors that need to be fixed. Again, Rydén states the importance of knowing how things work and doing what everyone is best at.

Another concern when performing surveying tasks with an excavator is the responsibility of errors. Who should be blamed for an error? The concern is also related to insurances. Even though the construction industry is very focused towards problem solving and everyone will do what they can when a problem is encountered, have the question of responsibility not been investigated by the industry according to Rydén.

9.1.5 When and how to use machine guidance systems

According to Rydén, there are no situations where machine guidance systems cannot be used. The system can likely measure several things but the actors difference in interest and focus makes it questionable if it should be used for everything it is intended to do. He states that you cannot ask a machine operator to work with AMA codes and plan a project, in the same way can you not install a GNSS system in a machine and believe that everything will work out fine.

Moreover, Rydén explains that there is a lower limit where machine guidance is not needed for a project and it is when the project is performed faster than the time it takes to create a model. There are several types of models that can be created, from simpler surface models, only showing the finished surface of a project or background models to more complicated models showing pipes, excavation bottom and more. Hence can models of different complexity be used and the model created for a project is dependent on the projects complexity and what the customer wants. Small projects might only need simpler surface model while larger projects might benefit from more complex models. More complicated models take longer time to create, maybe 150 hours. However, comparing the cost to if a surveyor would be on site everyday throughout the construction to perform setting out, a lot of money can be saved. Furthermore, the surveyor can then focus on other things important for the project, for example measuring in built construction objects, documentation of bedrock so the correct amount of bedrock excavation can be invoiced, etc. In addition, there is no need for a construction worker to work alongside the excavator, hence can this person focus on other tasks, for example the logistics and hence might more costs be saved.

Rydén presents a document created in 2013 where the company present how they want the machine operators to perform measurements with machine guidance systems in order for them to easily process the data. When creating the document their aim was to find the limit between what the machine operators can do and what the surveyors should do. However, it has been hard to get the information out to the customers and there seems to be no interest for it. The document explains that simple measuring in tasks can be performed by just clicking a button. More complicated measuring in tasks of for example, pipes, cables, or objects that should be regulated during the construction or presented to the client needs more planning and attention. Machine operator never sees the requirement list of how things should be measured, and hence do they often perform the measuring in task in the wrong way; measuring unnecessary things and forgetting about the important ones. If measuring things covered by a measuring and compensation rule[1], it is important to know what the rule says. Due to this the document include a list of what things to measure when measuring in more advanced components. The document also includes shortenings of objects and how files should be titled. Rydén continues and explain that their job is eased if their document is followed and that they easily can perform the last measurements needed and then process the data and create record drawings.

From their perspective is the ideal situation when the costumer involves them in an early stage of a project and asks them for suggestions regarding on how the surveying should be performed at the construction. When consulting them, they can suggest suitable models for machine guidance and suggest how the documentation and other measurements should be performed. A suggestion is a sort of start meeting where the client and surveyor discuss everything related to setting out, machine guidance system, terrain models or other files, control measurements, and measuring in etc. Rydén adds that a good example of this has been their project with Peab Asfalt where Peab Asfalt has got a turnkey contract to build a roundabout in Stenkullen and that they have been involved in the project since the start. Instead of first involving a project planner and creating a model with heights of everything has the surveyors focused on a water runoff model where they reassure that all water is collected by street inlets or ditches. From the model did they locate where street inlets were needed, and the model will be used by Peab Asfalt when building the roundabout. Moreover, it is not possible for them to be involved in such early stages in all projects, it is dependent on the type of contract. Some projects already have drawings when the contractor is given the contract.

9.1.6 Concluding comment

To conclude, Rydén is positive to machine guidance systems but state that it need to be used in the correct way and for the correct things. Surveyors have been in the industry for a long time, and their role will always be needed. The question is just for what and it is not possible to provide an answer to that question yet. It is important to find the limit between a surveyor and a machine operator with a guidance system, and not only from company to company but for the whole industry. Rydén adds that the only way to find the limit is to test it.

[1] *Measuring and compensation rule: Used when all or some objects in projects are adjustable and compensated for according to the real volumes, items and lengths etc.*

9.2 Company developing machine guidance systems

Leica Geosystems is a global company that has been working with measurement and information technologies for almost 200 years. The company provide services and products within for example surveying and engineering, and building and heavy construction. Their products include total stations, laser instruments, levelling instruments, GNSS systems, machine guidance and machine control systems etc.

The interviewee Rickard Juhlin (R.Juhlin, personal communication, March 9, 2018) is a product specialist at Leica Geosystems and works at the Infra division at the Gothenburg office.

9.2.1 Machine guidance systems

According to Rickard Juhlin is the three-dimensional machine guidance system the most common machine guidance system for excavators today. The system can be used for measuring in, setting out, and control of production by tracking the machine etc.. The systems GNSS unit is portable and allows for moving it to another machine while continuing using the system in a two-dimensional mode.

The measurement uncertainty of the GNSS unit in a machine guidance system is ± 20 millimetres and the measurement uncertainty of the sensors is ± 2 millimetres per meter system according to Juhlin. A three-dimensional system usually is around 14 meters giving a total accuracy in the size of an egg. The system with the shortest length gives the best accuracy theoretically. However, he adds that there is a difference in the systems accuracy and the actual result since other factors such as calibration of the buckets blade and the operators´ knowledge influence the result.

9.2.2 Development of machine guidance systems

Besides a development towards more automated machine systems Juhlin explain that there has been a focus on the transferring of data to and from the machine system. The development of digitally transferring data allows for data collection that can be used for example logging the number of truckloads of masses that have been moved from a project.

Moreover, the development of the European satellite system Galileo will improve the accuracy of machine guidance systems by having more reliable satellites available. The improvement will not be as large as when the Russian system Glonass became available, but the increasing number of satellites will allow for better measurements.

9.2.3 Usage of machine guidance systems

Rickard Juhlin explain that machine guidance systems can be used for setting out and measure in. The system can save a lot of time during construction but that it should not be used when a high accuracy on for example millimetre level is needed. When a higher accuracy is needed, it is recommended to control heights and measurements with other techniques.

According to Rickard Juhlin, the main limitation of machine guidance system is its operator. When using a machine guidance system, it is a surveying instrument. The machine operator must be given the right condition to perform measurements correctly. The operator is not a surveyor or an engineer. When measuring in, the operator normally does not know how or for what it is performed. Juhlin continues, that it is important to have one person at each measurement that can be responsible for and control or check that all measurements are correct and that the measurements are performed according to the guidelines available. He adds that it sometimes is inevitable to do double work, and sometimes must a surveyor perform measurements after a machine.

To conclude, Juhlin add that if the same machine operator has been used for a long time and the person is used to machine guidance systems, the possibility is great that the machine operator can perform all daily measurement, and thus can the double work be avoided.

9.3 Project planner, WSP Samhällsbyggnad

The interviewee David Gullberg (D. Gullberg, personal communication, March 28, 2018) works as a Team Manager at the division of land design at WSP Samhällsbyggnad in Stockholm. David finished his degree in civil engineering in 2005 at Chalmers University of Technology and has since then worked with project planning.

9.3.1 Project planners work with three-dimensional models

According to David Gullberg does WSP almost always produce three-dimensional models when projecting ground- and/or road projects. They do it for their own interest to control for example heights, and drainage or runoff from surfaces. The models are then used as the base for creating drawings. It is very unusual that these models are created after that the drawing has been made.

The step from their three-dimensional models to terrain models that can be used for machine guidance is relatively small. Files for excavation bottom and finished surface are already created while more complicated models need more modification. They mainly deliver CAD files in DWG or landXML format to the client. The client then uses their material direct in the machines or transform the material and create specific files for machine guidance.

9.3.2 Time, costs and requirements on three-dimensional models

More skilled CAD-designers that are used to the programs creates three-dimensional models faster than it takes to create traditional drawings. When producing three-dimensional models, they follow the requirements set by the client. When no requirements exist do they create as simple models as possible yet are in line with the accuracy that can be achieved on a construction site when using traditional drawings. The requirements given are both related to content in the files, accuracy and sometimes also how the coding should be performed. Gullberg adds that there is no use in creating models with higher accuracy than the in-data, for example data of the existing surface.

Gullberg adds that a model for machine guidance becomes expensive when it should fulfil specific requirements and be used for more than setting out. As an example, it is time demanding to produce models with details such as edge support in crossings, bus stops, transitions between different superstructures, and other things that is not included in a standard normal section. In addition, special coding of objects is time demanding since their programs cannot name the objects as the requirements tells. They need to rename objects separately and David Gullberg cannot see the profit from it since the coding is not used in field when the machine operator uses the models.

9.3.3 Validity of construction documents

When the planners are finished with the models or drawings are they approved by the project manager and then sent to the client for approval. The client performs a control of the delivered documents and signs that the documents are approved or not. According to Gullberg does WSP consider the construction documents approved by the client to be valid for a construction. This means that if drawings are delivered and approved, they are the documents that should be followed. Furthermore, if a pure model delivery is approved, WSP take full responsibility for that the information in the models are correct. Moreover, it occurs that the drawings and models differ and that they end up in disagreement with the contractor regarding responsibility. The project planners' base statement is that if a client has approved the drawings and not the models, it is the drawings that are valid for the project.

According to Gullberg are models harder to control and there is no standard for how models should be inspected. In, addition if the client approves the models, it should be clearly stated.

9.3.4 The advantages of three-dimensional models and when to use it

According to Gullberg, there are only advantages to three-dimensional models and planning in 3D. As previously mentioned, skilled CAD-planners create three-dimensional models faster than the time it takes to create traditional drawings. In the same time does the model creation allow the planners to plan correct from the beginning and less things have to be redesigned. It is only for very small projects for example, parking lots or approach streets that they work with traditional two-dimensional projection.

9.4 Site manager, Peab Asfalt

Johan Gustafsson (J. Gustafsson, personal communication, April 19, 2018) work as a site manager at ground construction projects at Peab Asfalt. Gustafsson finished his education in construction engineering 11 to 12 years ago and started working with surveying. He worked with surveying for three years before being promoted to site manager. Today, he has been working as a site manager for approximately eight to nine years. Around four to five years ago did he start to use machine guidance systems more thorough on his projects. Before that had he used the systems on some projects.

9.4.1 How machine guidance systems are used on the projects today

On Gustafssons construction projects today are mainly three dimensional GNSS systems used, but sometimes are also systems with total stations used. The machine guidance systems are used for some setting out but mainly as a support in the production by allowing the machine operator to get an overall view of the project. From his experience can the systems not be used for documentation and calculations of masses covered by a measuring and compensation rule, at least not for the Swedish Road Authority or similar clients.

Today, they do not use the systems for measuring in or setting out objects related to fine planning. These tasks are performed by surveyors since the systems do not have enough accuracy or enough information in the models to perform the tasks. One example of when the information in the files are not enough are when setting out curb stones next to a street inlet. The curb stone need to be positioned alongside the edge of the inlet. The machine operator can only see the street inlets centre and not the size of the cover to the inlet. Hence can the curb stones position not be set out by the machine operator. Moreover, surveyors and manual surveying are used when the files or models for the machine guidance systems are not finished in time. Sometimes will a project start before there has been time to produce the files needed for the machine guidance system and hence can the system not be used. The answer to why surveyors are needed on projects where machine guidance systems are used might be that the knowledge of the machine operators are not enough.

9.4.2 Benefits and disadvantages when using machine guidance systems

Gustafsson initially state that he only sees benefits with using machine guidance systems. The machine operators become more self-acting, and the project can proceed better. In addition, less questions regarding the project and the things that should be done arise and asked to him. When using the systems can the machine operators see what should be perform and hence can the operators plan the daily or weekly work more by themselves. For example, by seeing how much masses that needs to be excavated, the machine operator can get an approximate number of trucks needed for transporting the material. Furthermore, if problems occur, for example if bedrock is uncounted, it is easier for the machine operator by him-/herself to see other tasks that needs to be performed on other locations at the construction site. Hence, there will be less production stops while the problem is solved.

According to Gustafsson, the systems are very good tools for large excavations and long pipe and cable excavations. When excavating bedrock, it is important not to excavate too deep since blasting works are costly. Excavation of clay material is even more expensive since the material needs to be deposited and a deposition fee will be added to the excavated masses. Hence are machine guidance systems a good tool for excavation tasks.

Moreover, Gustafsson can see a disadvantage in that it is harder for him to see how the project is according to the plan. Since there are no markers that can direct him in the things that are left to do it is harder for him to recognise the progress. For example, on road constructions, there are no markers of where the road will end. Gustafsson adds that it only is a small disadvantage since he can get that information from speaking to the machine operators.

Another drawback is that there is a risk that the machine operators rely too much on the system and loses the attention of checking for errors. If the operator completely follows the model, there is a risk that errors are not seen and that the construction goes wrong. However, the model or files used for the machine guidance systems are always created by a surveyor for their projects. The surveyor can then be seen as an extra pair of eyes to check for errors when creating the model. But mistakes can always be made, so there is always a risk of errors, especially if the machine operator lose the feeling or stops considering the reasonableness in what the system is showing.

9.4.3 Requirements from the client

Johan Gustafsson has never seen that a client has required that machine guidance systems should be used on a project. Even work that has been performed for the Swedish road authority have not had such demands. On the other hand, he believes that it can be more common on the asphalt segment. However, the clients usually have requirements on the accuracy on projects which affects the choice of surveying tool.

9.4.4 How to use machine guidance systems in the future

According to Gustafsson, surveyors and manual surveying will always be needed. Some tasks such as measuring in and setting out of specific details will never be performed accurate enough with a machine guidance system. However, it would be ideal if the system could be used to perform all or almost all setting out task.

In addition, it would be helpful if the machine operators could perform the measuring in tasks of their excavations and fillings by themselves and that the information could be sent to the surveyor direct trough the control box. Then the surveyors would not have to go out on site as much to get the correct amount of excavation of filling for each month. Instead, they can calculate the volumes from the files created by the machine operator. If the machine operators could perform these measurements themselves, the surveyors would be able to support more project simultaneously.

9.5 Machine Operator of machine guidance systems

Sebastian Henriksson (S. Henriksson, personal communication, April 20, 2017) has been working as a machine operator for excavators during the last three years. He studied at a construction program during upper secondary school where they had a course in machine guidance systems. However, the course was intended for people who had used the systems earlier, which they had not. Henriksson has learned the systems himself through using them since the beginning of his carrier as a machine operator.

9.5.1 The usage of machine guidance systems

Sebastian explains that he has used machine guidance systems based on GNSS technology, laser and total stations. From his perspective as a machine operator, the only difference is the accuracy in the system and the coverage or strength of the signal. GNSS systems for example, do not have good signal reception in areas with high trees. On project he has been involved in they have used the systems for setting out, measuring in and sometimes only as guidance parallel with manual surveying.

When using the systems, initially a fix point is set out by a surveyor which the operator can use to control the systems settings and calibration. The calibration for the blade is performed around every fourth month, and the calibration of the whole system is performed around every to every other year. In addition, it is important to check that the correct channel is used for collecting the correction signal for the GNSS systems. If the wrong channel is used, the correction data will be wrong, and hence will all guided levels be incorrect.

9.5.2 Concerns and usual errors or problems

Henriksson explain that the most common problem is that the model used for the project is unclear and too much information is given in it. Hence it becomes hard to interpret the model. In addition, it is common that they initially only have a model of the excavation bottom and only later get models or files with information regarding cables and pipes. From his perspective as a machine operator, it would be good to have all models from the beginning, so he can start with the excavation for the cables simultaneously as he excavate for the excavation bottom or at least know where it should be located.

9.5.3 Development potential and future use of machine guidance systems

Henriksson believes that the systems are quite well developed today and cannot come up with an answer regarding the systems development potential straight away. After some minutes, he adds that he can see a potential in having more accurate systems so the setting out and measuring in of pipes and water head can be performed. In addition, it would be good if the signal coverage of GNSS systems would increase so the signal becomes better on projects surrounded by high trees or buildings. More specific improvements would be that it would be possible to zoom in on points for example street inlets to see that objects coordinate. Today it is only possible to zoom in where the machine is operating, not on positions located further away. If a construction worker asks him about specific objects position he must move the excavator to that point before being able to zoom in and look at the object close up in the model.

On the question of what surveying tasks a machine operator can and cannot perform does he not have a specific example but believes that surveyors always need to be involved in projects. For example, even if the machine guidance systems are developed and all setting out and measuring in tasks can be performed by the machine operator, it would be good to have surveyors that perform control measurements. This to minimize the risk of errors.

9.6 Corporate adviser on insurances

The interviewee Babak Mobaraki (B. Mobaraki, personal communication, April 25, 2018) works as a corporate advisor on insurances at Länsförsäkringar.

9.6.1 Insurances for machine operators and surveyors

According to Babak Mobaraki does companies that rent out construction machines and machine operators need two types of insurances. Initially is a liability insurance needed for persons and property damage, but additionally is an insurance for all the machinery and damages on those needed.

A surveyor need a technical consultation insurance. This insurance can cover different aspects, so the company usually let the costumer fill in a questionnaire to get the correct protection. When a machine operator performs surveying tasks with a machine guidance system, the traditional liability insurance and machine insurance is not enough. An additional consulting liability insurance is needed.

10 Analysis of Accuracy and Tolerances

From the definitions of accuracy and mean deviations by (Lilje, n.d.; Swedish Standards Institute, 2016), it was found that the accuracy of the systems and the tolerances expressed as mean deviations, likely indicate the same thing, hence are comparable. Though, it is not only the systems accuracy that needs to be considered; the reference networks are also associated with uncertainties. These are often stated as additional factors to the equipment's´ uncertainty. For example, the term *"± X ppm"* means that for every kilometre of distance between the reference station and location of measurement, 1 millimetre will be added to the uncertainty.

According to Rickard Juhlin, the accuracy of a machine guidance systems GNSS unit is around ± 20 millimetres in the vertical direction. In addition, the sensors on the boom, stick and bucket etc. have an accuracy of ± 2 millimetres per meter system. The systems usually have a length of 14 meters. However, according to a technical specification of a GNSS receiver from Leica Geosystems, the accuracy with RTK measurements are 8 millimetres + 1 ppm in the horizontal direction and 15 millimetre + 1 ppm in the vertical direction. The sensors accuracy is not given in Leica Geosystems technical descriptions but by using the accuracy stated by Juhlin can the following accuracy be assumed for a machine guidance system:

Horizontal direction:
GNSS accuracy: 8 millimetres + 1 ppm
Sensor uncertainty: 2 millimetres per meter
Length: 14 meters
Total accuracy: $8\ (+1ppm) + (2 \cdot 14) = 36\ mm + 1\ ppm$

Vertical direction:
GNSS accuracy: 15 millimetres + 1 ppm
Sensor uncertainty: 2 millimetres per meter
Length: 14 meters
Total accuracy: $15\ (+1ppm) + (2 \cdot 14) = 43\ mm + 1\ ppm$

According to figure 7, the distances between the Swepos stations are 35 kilometres in the area of Gothenburg. The maximum distance to a station can hence be 17.5 kilometres. By assuming a distance of 17.5 kilometres can the total accuracy of a machine guidance system be assumed:

Horizontal accuracy: 36 + 17.5 = 53.5 millimetre
Vertical Accuracy: 43 + 17.5 = 60.5 millimetre

By comparing these values with mean deviations for setting out, Table 7, the accuracies only comply with the maximum allowed mean deviations for setting out of road area, clearance and vegetation removal. When comparing the systems accuracy with allowed measurement uncertainties for measure in, Table 9, all measurement uncertainties are lower, hence no categories can be measured in. If instead using RTK corrections from Swepos stations, the additional factors will be as presented in Table 2. Then, if assuming a grid density of 35 kilometres and a distance of 17.5 to the closest station, the additional factors will be 10 millimetres in plan and 18 millimetres in height. Giving a total horizontal accuracy of 46 millimetre and a vertical accuracy of 61 millimetre. Yet, the same result is achieved; only road area, clearance and vegetation removal can be set out, and no measure in.

If a local reference is created at the construction site, the additional factors can be eliminated. The accuracy will then be 36 millimetres in the horizontal direction and 43 millimetres in the vertical. Still, only road area, clearance and vegetation removal would be possible to set out. On the other hand, when using a system with laser, the accuracy will be decreased to 3 to 6 millimetres in the vertical direction. When using a machine guidance system with a total station, the accuracy will be 2 to 5 millimetres. Then all setting out can be performed with the system. For measure in only corner of houses, ditches and slopes, gravel roads, retaining walls, fences, trees, gravel surfaces, grass surfaces, pipes and cables in open trenches, natural land and bedrock surfaces comply with the accuracy in the system.

11 Case Study

The case study was performed at a ground construction project near Oljebergsvägen in Gråbo, Lerum Municipality in Sweden, se Figure 12. Peab Asfalt AB has been selected to perform the ground construction works in a partnering contract with Myressjöhus. (J. Gustafsson, personal communication, April 17,2018) The worksite is 16,000 square meter which initially consisted mainly of bedrock to the surface.

Figure 12. Location of Gråbo, marked with a black cross. (© Lantmäteriet, 2018)

Myressjöhus is the project developer and the development consist of 11 ground plots, se Figure 13 for schematic Figure of the plots. (J. Gustafsson, personal communication, April 17, 2018) The ground construction started in the end of March in 2018 and is planned to be finished in mid-October 2018. The project is planned to maximise the usage of machine guidance systems. The workers involved in the project today can be seen in Table 10.

Table 10. Construction workers at the Gråbo project in May 2018. Author´s own Copywrite.

Profession	**Amount of workers**
Site manager	1
Supervisor	1
Surveyor	1
Machine operators	2
Blaster	2
Truck drivers	Varying day to day

Figure 13. Schematic figure of the 11 planned plots near Oljebergsvägen in Gråbo. (Lerum Kommun, n.d)

Initially, the existing surface of the area was measured in with manual surveying by Emil Hjertberg, a surveyor from Trig. (E. Hjertberg, personal communication, May 17, 2018) Hjertberg has also created the models that will be used in the project. The project is currently in the blasting process and the heights for the blasting is set out manually by Hjertberg. Simultaneously as the blasting progresses are two machine operators excavating to excavation bottom and for this is a model of excavation bottom followed. Due to unforeseen problems with the blasting was the project delayed.

The plan for the following work is that the machine operators will perform cable and pipe excavations after a model containing information regarding the layout of these. (E. Hjertberg, personal communication, May 17, 2018) For this will only the machine guidance systems as well as a construction laser with a levelling instrument, used by a construction worker be used. Furthermore, all fillings will be performed by the machine operator by using the guidance systems. No measure in will be performed with the machine guidance systems. Instead, all measure in will be performed by a surveyor when the project is finished.

12 Discussion and Recommendation

With machine guidance systems can both surveyors and machine operators perform surveying. According to Tobias Rydén, owner at the surveying company Trig, has this led to a situation where the roles of the two professions are unclear. Due to this is parallel work possible. The question of how much parallel work occurs is hard to answer since it is very dependent on the knowledge of the project management and machine operator, time frame and planning, as wells as type of project. However, according to Johan Gustafsson, site manager at Peab Asfalt, are the machine guidance systems mainly used for guidance and support in the production, and also some setting out. Hence, not for all tasks the developer state them to be developed for. This is supported by the project study which also showed that the systems are not fully used. Since the systems often are used as guidance is manual surveying also needed. The question of who can or who should perform what has not been investigated according to Rydén. Therefore, it is interesting to investigate how surveying and machine guidance systems can be used at construction sites. The thesis has been limited to focusing on the areas of regulations and insurances, technical aspects, knowledge and time and costs. These areas will be discussed in the following chapters.

12.1 Regulation and insurances

The first focus area has been to answer if surveying with machine guidance systems are accepted to be used for surveying. From the interview with Rydén, it was found that an additional insurance was needed by to being able to perform surveying tasks with the excavator. A further interview was held with Babak Mobariaki who work as a corporate adviser on insurances at Länsförsäkringar. He stated that machine operators today usually have a liability insurance covering personal and property damage as well as an insurance covering the machines. He stated that an additional technical consultant insurance was needed if surveying tasks such as setting out or measure in was to be performed with a construction machine.

Furthermore, from the interview with Gustafsson, it has been found that the systems are not accepted to be used for measure in to create relation drawings or for calculations and documentation for measuring and compensation rules. At least not for clients as the Swedish Road Authority.

12.2 Technical aspect

The technical aspect was analysed by comparing tolerances for setting out and measure in with the different machine guidance systems accuracy. It was found that the tolerances for setting out only is a theoretical value and not used for choosing a method for a surveying task. According to the Swedish Standard, SIS-TS 21143:2016, appendix D.2 should the tolerances instead be converted to values of maximum allowed mean deviations. These values were then compared to the different systems approximated accuracy. However, the real mean deviations of the systems measurements vary depending on for example number of available satellites, atmosphere and tropospheric conditions, distance to reference stations etc. The analysis can therefore only give indications of when the systems might be able to be used.

When assuming a distance of 15 kilometres to the nearest reference station, the accuracy of a GNSS based machine guidance system was estimate to 51 millimetres in the horizontal direction and 58 millimetres in the vertical. Then the accuracies only complied with the maximum allowed mean deviations for setting out of road area, clearance and vegetation removal. For measure in, all allowed measurement uncertainties were lower, resulting in that no categories were able to be set out. Even when using RTK corrections from Swepos, or assuming a distance of 0 kilometres to the reference station were the same result achieved. On the other hand, when using a system with laser, the accuracy can be decreased to 3 to 6 millimetres in the vertical direction. When using a machine guidance system with a total station, the accuracy is 2 to 5 millimetres. Then all setting out can be performed with the systems. For measure in only corner of houses, ditches and slopes, and gravel roads comply with the allowed uncertainties. As well as, retaining walls, fences, trees, gravel surfaces, grass surfaces, pipes and cables in open trenches, natural land, and bedrock surfaces.

To summarise, a GNSS based machine guidance system do not have enough accuracy to perform most of the measurements. On the other hand, several surveying tasks can be performed when adding a laser receiver or total stations to the system.

12.3 Knowledge

In the interviews, several actors stated that it was not the system's accuracy that restricted the use of the system but the machine operators' knowledge. Hence, the question of knowledge was investigated more trough the following interviews. The topic was initially brought up by Rydén, who stated that the vision of machine guidance is good but that the machine operator limits the usage. Surveyors have been educated in measurement standards and requirements the measurements should fulfil, while the machine operator has not. Furthermore, there is also a difference in focus; surveyors have the focus towards documentation and machine operators have the focus on the production. Hence will there be a difference in result when performing the same tasks. Rickard Juhlin, a product specialist as Leica Geosystems, also stated that the machine operator limits the usage of the system. He stated that there is a difference in what the systems technically can-do accuracy wise, and what is possible in reality. However, he also stated that machine operators that are used to the systems are likely to be able to perform several surveying tasks. Still, surveyors will be needed for control measurements and some specific measurements that the machines are not able to perform. In the interview with Gustafsson, he stated that the reason for why surveyors still are needed when using machine guidance systems, might be that the knowledge of the machine operators is not enough. Moreover, Sebastian Henriksson, machine operator, did not have a specific example on what surveying tasks a machine operator cannot perform, but believed that surveyors always need to be involved in projects. He stated, even if machine guidance systems were developed and all setting out and measuring in tasks could be performed by the machine operator, it would be good to have surveyors that perform control measurements, to minimize the risk of errors. This was also brought up by Rydén and Gustafsson.

Rydén brought up an example of measuring in existing surfaces that later will be used for mass calculations and/or measuring and compensation rules. When measuring in an existing surface, it is important to plan the measurements to get a correct model of the real surface. Otherwise will the mass calculations performed with the model give a different result compared to reality. This might lead to that less masses than actually excavated is said to be excavated and hence might lead to a loss of income. Moreover, measuring in tasks that have been performed without a plan or conversation with a surveyor might lead to that the measurements are not performed as the surveyor would like them to be. Hence it might become hard or impossible to process the data since the surveyor do not know how the machine operator thought or performed the measurements. It might lead to that the measurements are time consuming or even impossible to use for performing record drawings.

12.4 Time and costs

From the perspective of time and costs it was found that some surveying tasks are too time consuming to perform with a machine guidance system. Rydén gave the example of measuring in of existing surfaces. He questioned if it was reasonable that a machine operator with machine guidance system costing 1200 SEK per hour should measure in an existing surface when a surveyor costing around 600 to 700 SEK per hour could perform the same task as fast or even faster. He also added, that the main task of an excavator is to excavate as fast as possible since other workers will for example lay pipes afterwards. When analysing this perspective, it is clear that the surveying performed with machine guidance should be performed without unnecessary interruptions in the progress of the constructions. If construction workers are dependent on the immediate progress of the excavator, it is not suitable to stop the excavation and perform measuring in tasks.

12.5 Roles of machine operators and surveyors

Surveying has traditionally been related to the determination of the three-dimensional position of points on or near earth's surface by measuring distances and angles. Surveyors have been the professional workers to perform these tasks. In construction projects, they have traditionally performed measurements with electric distance meters, theodolites, levels. With the development of new technologies such as GNSS systems and machine guidance systems has the definition of surveying and the tasks of a surveyor changed. Today is surveying instead defined as the collection, processing and managing of spatial information and most measurement are performed as relative positioning with GNSS based total stations. Furthermore, from the interview and project study, it has been found that less measurements are performed by surveyors and more time is spent on supporting tasks to the machine guidance systems, for example creation of files for the machine guidance system, set up the system and load files to the machine, and support the operator in questions related to surveying.

From analysing the systems accuracies with allowed mean deviations when setting out and measure in, it was found that almost no measurements performed with GNSS based systems comply with the allowed mean deviations. Systems using laser or total stations allowed for more measurements to be performed. In the future is it possible that the systems become more accurate, and that more measure can be performed by machine operators and hence might even less measurements be performed by surveyors. Still, the surveyors will never be fully replaced by machine guidance systems. Surveyors will be needed for control measurements, measurements where the system cannot be used or specific measurement where the accuracy of the system is not enough.

Machine operators have traditionally operated different machines on construction projects that have been used for example excavation, loading and unloading. Today is their main task the same, however has the development of machine guidance made it possible for them to perform surveying tasks. It varies from project to project if machine guidance is used for pure surveying tasks or if it only is used for guidance, parallel with traditional surveying. In projects where the systems are used for surveying will the machine operator get increased responsibility and consequently a more important role. A machine operator with good knowledge of the systems is likely to perform several surveying tasks to a satisfying standard and increase the production rate while in contrast an operator new to the system might not be able to perform as much or as well as required. To summarise, the machine operators' role will be dependent on their knowledge and interest to learn the system.

12.6 General discussion

The question of how the systems should or can be used is complex and a general answer is hard to get. The usage will vary from project to project depending on the knowledge and interest of the personnel involved. Yet, from analysing the four aspects and assuming that a machine operator with good knowledge of the systems is used, machine guidance can be used for simple setting out tasks. For example, soil and rock excavations/filling to excavation bottom, vegetation removal, slopes and breakpoints, ditches, and subbase. Since an additional levelling instrument often is used by the ground constructors when laying pipes or street inlets, might these tasks also be performed without a surveyor. Some measure in tasks can also be performed if the client accepts it, but the knowledge of the machine operator is crucial. Then a surveyor only needs to measure in the objects that will be visible at the surface. However, the surveyor responsible for data processing and the last measurements that the machine guidance system cannot perform must be involved in the process to be able to understand and process the data collected by the machine operator. Good communication with the surveyor is important.

Tasks requiring more precise measurements and knowledge is recommended to be performed by surveyors. Even if systems with laser or total stations are used that comply with the tolerances are some tasks still needed to be performed by a surveyor. Examples of these measurements are measure in of existing surfaces, setting out of piles, foundations, and surface layers in road constructions, and sometimes also cables and pipes. In addition, all fine planning requires setting out by a surveyor, for example curb stones. When a machine operator new to the systems is used, it recommended that all measure in tasks are performed by surveyors. This to avoid measurement errors in the files that might be used for mass calculations. A surveyor is also needed for control measurements.

Yet, it is important to note that the use of machine guidance systems may have higher uncertainties and that errors might occur more easily, especially when the system is used by someone with low knowledge of it. For example, errors in the settings of the coordinates system in the machine can result in that all measurements will be incorrect. In addition, there is a risk that the machine operator relies too much on the system and forget to think by him-/herself. Therefore, it is important to have a surveyor that helps with the set-up of the system, and conduct control measurements.

Moreover, good planning and possibly a start meeting with a surveyor before the project start is the foundation to successful usage of machine guidance system. A well-structured plan of what surveying tasks the machine operator should do and what tasks a surveyor must do will minimize the double work. During the start meeting, the machine operator and surveyor can discuss how the measurement with the machine guidance systems should be performed in order for the surveyor to process the data. In addition, it is also important to plan what models or files the project is in need of for the machine guidance. If all models are produced before the construction start will the machine operator likely be able to perform the construction more efficient. Henriksson stated that the files for pipes and cables sometimes are delivered when the project already has started and that an improvement would be to have all files at the start of the project. It allows for preparation of work that should be performed at a later stage. For example, excavation for pipes can be performed simulates as the excavation bottom for a road or foundation is created.

12.7 Method

The thesis was performed through a literature-, interview- and project study. The literature study has mainly been based on information from books regarding geodesy and surveying, organisations as Byggforskningsrådet, Lantmäteriet, Svensk Byggtjänst, Swedish Standards Institute, and information from developers of machine guidance systems. Information from the developers of the systems have been seen as more unreliable since it might be more one-sided, hence has it mainly been used for technical information regarding machine guidance systems. In addition, web sources have also been used, which might be more unreliable than published information. However, information that has been considered unsure has either been supported with interviews or that several sources has provided similar information.

In total were six in depth interviews held with a surveyor, technical specialist at a company developing machine guidance systems, project planner, site manager, machine operator and a corporate advisor on insurances. The interviews provided a good foundation to the four perspectives that have been investigated. That the interviews took place as semi-structured interviews and that the questions were adapted to the interviewer during the interview have been considered not to have affected the result. In addition, the questions to the different actors were not equal since the actors have different knowledge and interests. For example, the user-friendliness and common errors in the production cannot be answered by a project planner. Rather, the questions of interest have been clarified more toughly and further aspects that would not have been brought up was added, by performing semi structured interviews.

The limited selection of people interviewed might have affected the result. More actors could have been interviewed but the interviewed actors have been considered to have the most central roles when working with machine guidance systems. That only one interview was conducted with each professional group could have affected the result since only one person´s thoughts and opinions came to speech. More people from the same professional group should have been interviewed but this was not possible due to limitations in time.

The project study was delayed due to unforeseen reasons in the blasting process. This resulted in that the study could not be performed as planned. The plan was to test the usage of machine guidance when minimizing the use of traditional surveying. But as in May 17th, 2018, the project had only used the system for creation of the excavation bottom. Hence can the systems performance not be analysed as intended. Instead, the project study was focused on how the surveying has been performed in the project and how the remaining tasks are planned to be performed.

12.8 Further research

Tobias Rydén stated that the only way to investigate where the limit between a surveyor and machine operator using machine guidance systems is, is to test it. The project study in this thesis was planned to do so to some extent, but due to the delay were the plans changed. Further studies of testing the systems fully while minimizing the traditional surveying is therefore of interest for further studies.

13 Conclusion

The study has found that parallel work with machine guidance systems and surveyors can be avoided to some extent. Machine guidance systems cannot be used for all surveying tasks and hence is surveying still needed.

The roles of surveyors and machine operators have and will continue to change with the development of machine guidance systems. Today, surveyors perform less measurements on the construction sites and more time is spent on supporting work to the machine guidance systems, for example creating files and mass calculations. The main surveying tasks of a surveyor will be control measurements, measure in, and setting out of some specific details. With time will likely measure in also be performed with machine guidance systems or other technologies. Moreover, machine operators get more responsibility when using machine guidance systems and will hence have a more important role in projects. Besides performing their traditional tasks of excavation and filling can they perform most of the setting out and some measure in tasks. However, their role will be dependent on their knowledge and willingness to learn the system.

Knowledge and planning are important parts for successful usage of machine guidance systems. A well-planned project where the work roles of surveyors and machine operators are clearly defined and a machine operator who has good knowledge of the systems will contribute to avoiding double work, and hence can time and costs be saved.

14 References

Aðalsteinsson, D. H. (2008). *GPS machine guidance in construction equipment*. (Master´s thesis, Reykjavík University, School of Science and Engineering.

Arbetsförmedlingen. (2017a). Anläggningsarbetare. Retrieved April 26, 2018, from https://www.arbetsformedlingen.se/For-arbetssokande/Yrke-och-framtid/Yrken-A-O.html?url=1119789672%2FYrken%2FYrkesBeskrivning.aspx%3FiYrkeId%3D7&sv.url=12.78280711d502730c1800072

Arbetsförmedlingen. (2017b). Anläggningsmaskinförare. Retrieved April 25, 2018, from https://www.arbetsformedlingen.se/For-arbetssokande/Yrke-och-framtid/Yrken-A-O.html?url=1119789672%2FYrken%2FYrkesBeskrivning.aspx%3FiYrkeId%3D697&sv.url=12.78280711d502730c1800072

Berntsson (2011) *Maskinstyrning på småskaliga markentreprenader*. (Master´s thesis, Chalmers tekniska högskola, Institutionen för bygg- och miljöteknik.

Breach, M. (2014). Surveying instruments. Retrieved February 18, 2018 from https://doi.org/10.1036/1097-8542.757384

Byggforskningsrådet. (1998a). *HMK Bygg och Anläggning, Byggande, BA4* (T23:1998). Stockholm: Byggforskningsrådet.

Byggforskningsrådet. (1998b). *HMK Bygg och Anläggning, Projektering, BA3*. Stockholm: Byggforskningsrådet.

Byggledarskap. (2014). *Roller och yrken i byggprojekt*. Retrieved April 25, 2018 from http://byggledarskap.se/samlade-dokument/

Carlsson, C., & Tidholm, M. (2013). *Maskinstyrning, Maskinstyrning och dess användning ur ett geodetiskt perspektiv*. (Master Thesís, Karlstads Universitet)

European GNSS Agency. (2016). European Global Navigation Satellite System Agency: FAQ. Retrieved February 14, 2018, from https://www.gsa.europa.eu/european-gnss/galileo/faq

European Space Agency. (2018). What is Galileo? Retrieved February 2, 2018, from http://m.esa.int/Our_Activities/Navigation/Galileo/What_is_Galileo

Fosburgh, B. (2011). Construction : The five-dimensional world. Retrieved January 17, 2018 from https://www.geospatialworld.net/article/construction-the-five-dimensional-world/

Granhage, L. (2011). *Kompendium i Geodesi*. Göteborg: Chalmers Tekniska Högskola.

Hedin, A. (2011). *En liten lathund om kvalitativ metod med tonvikt på intervju*. (C. Martin, Ed.).

Jack McCormac. (2004). *Surveying* (5th ed.). John Wiley & Sons.

Johansson, R., & Öster, T. (2011). *GNSS-instrumentets möjligheter och begränsningar vid vägbyggnation Possibilities and limitations of the GNSS instrument in road construction*. (Master´s Thesis, Tekniska Högskolan i Jönköping)

Jonsson, H. (2008). *Satellitguidning av grävmaskiner*. (Master´s Thesis, Luleå Tekniska Universitet, Instutionen för Samhällsbyggnad)

Lantmäteriet. (1996). *Handbok, Geodesi, Detaljmätning*. Gävle: Lantmäteriet

Lantmäteriet. (2015). *HMK, handbok i mät- och kartfrågor, Geodesi: Terrester Mätning*. Retrieved February 2, 2018 from https://www.lantmateriet.se/globalassets/om-lantmateriet/var-samverkan-med-andra/handbok-mat--och-kartfragor/geodesi/hmk-ge_terrester_2015.pdf

Lantmäteriet. (2017a). *HMK, handbok i mät- och kartfrågor, Geodetisk infrastruktur 2017.* Retrieved January 18, 2018 from https://www.lantmateriet.se/globalassets/om-lantmateriet/var-samverkan-med-andra/handbok-mat--och-kartfragor/dokument/2017/hmk-geinfra_2017.pdf

Lantmäteriet. (2017b). *HMK, handbok i mät- och kartfrågor, Terrester detaljmätning 2017*. Retrieved January 18, 2018 from https://www.lantmateriet.se/globalassets/om-lantmateriet/var-samverkan-med-andra/handbok-mat--och-kartfragor/dokument/2017/hmk-terdet_2017.pdf

Lantmäteriet. (2017c). *HMK, handbok i mät och kartfrågor, GNSS-baserad detaljmätning 2017.* Retrieved January 19, 2018 from https://www.lantmateriet.se/globalassets/om-lantmateriet/var-samverkan-med-andra/handbok-mat--och-kartfragor/dokument/2017/hmk-gegnss-det_2017.pdf

Lantmäteriet. (2017d). *Vad är geodesi, 1(9), 1–9.* Retrieved January 18, 2018 from https://www.lantmateriet.se/globalassets/kartor-och-geografisk-information/gps-och-matning/geodesi/vad_ar_geodesi.pdf

Lantmäteriet. (2018a). *Avståndsmätning med bärvåg.* Retrieved February 5, 2018, from https://www.lantmateriet.se/en/Maps-and-geographic-information/GPS-and-geodetic-surveys/GPS-och-satellitpositionering/Metoder-for-GNSS-matning/Avstandsmatning-med-barvag/

Lantmäteriet. (2018b). *DGNSS.* Retrieved February 6, 2018, from http://www.lantmateriet.se/sv/Kartor-och-geografisk-information/GPS-och-geodetisk-matning/GPS-och-satellitpositionering/Metoder-for-GNSS-matning/dgnss/

Lantmäteriet. (2018c). *Glonass.* Retrieved February 1, 2018, from http://www.lantmateriet.se/sv/Kartor-och-geografisk-information/GPS-och-geodetisk-matning/GPS-och-satellitpositionering/GPS-och-andra-GNSS/Glonass/

Lantmäteriet. (2018d). *GPS och satellitpositionering.* Retrieved February 1, 2018, from http://www.lantmateriet.se/sv/Kartor-och-geografisk-information/GPS-och-geodetisk-matning/GPS-och-satellitpositionering/

Lantmäteriet. (2018e). *Införande av SWEREF 99 och RH 2000.* Retrieved February 1, 2018, from http://www.lantmateriet.se/sv/Kartor-och-geografisk-information/GPS-och-geodetisk-matning/Referenssystem/Inforande-av-SWEREF-99-och-RH-2000/

Lantmäteriet. (2018f). *Nätverks-RTK.* Retrieved February 6, 2018, from http://www.lantmateriet.se/sv/Kartor-och-geografisk-information/GPS-och-geodetisk-matning/GPS-och-satellitpositionering/Metoder-for-GNSS-matning/Natverks-RTK/

Lantmäteriet. (2018g). *RH 2000*. Retrieved February 1, 2018, from http://www.lantmateriet.se/sv/Kartor-och-geografisk-information/GPS-och-geodetisk-matning/Referenssystem/Hojdsystem/RH-2000/

Lantmäteriet. (2018h). *RTK*. Retrieved February 6, 2018, from http://www.lantmateriet.se/sv/Kartor-och-geografisk-information/GPS-och-geodetisk-matning/GPS-och-satellitpositionering/Metoder-for-GNSS-matning/RTK/

Lantmäteriet. (2018i). *Statisk mätning med efterberäkning*. Retrieved February 6, 2018, from http://www.lantmateriet.se/sv/Kartor-och-geografisk-information/GPS-och-geodetisk-matning/GPS-och-satellitpositionering/Metoder-for-GNSS-matning/Statisk-matning-med-efterberakning/

Lantmäteriet. (2018j). *SWEREFF 99*. Retrieved January 31, 2018, from http://www.lantmateriet.se/sv/Kartor-och-geografisk-information/GPS-och-geodetisk-matning/Referenssystem/Tredimensionella-system/SWEREF-99/

Lantmäteriet et al. (2013). *Geodetisk och fotogrammetrisk mätnings- och beräkningsteknik.* Lantmäteriet m.fl.

Leica Geosystems AG. (n.d.). *Leica iCON gps 80, Increasing productivity, Maximising uptime*. Heerbrugg, Switzerland. Retrieved March 8, 2018 from https://www.lantmateriet.se/globalassets/kartor-och-geografisk-information/gps-och-matning/geodesi/rapporter_publikationer/publikationer/felteori_artikel_sinus_2004_nr_3.pdf

Leica Geosystems AG. (2014). *Leica Geosystems intelligent CONstruction*. Heerbrugg. Retrieved March 8, 2018 from file:///D:/Users/Desiree.DP_DATOR/Downloads/Leica_MC_Solution_BRO.pdf

Lennartsson, H., & Åberg, S. (2009). *Profitability with machine control*. (Master´s Thesis, Tekniska Högskolan i Jönköping)

Lilje, M. (n.d.). *Vad är rätt och vad är fel?* Retrieved May 14, 2018 from https://www.lantmateriet.se/globalassets/kartor-och-geografisk-information/gps-och-matning/geodesi/rapporter_publikationer/publikationer/felteori_artikel_sinus_2004_nr_3.pdf

Machine Guidance. (2018). *Machine Guided Construction - Challenges.* Retrieved March 5, 2018 from https://machineguidance.com.au/Machine-Guided-Challenges.

Merriam Webster. (2018). *Geodesy*. Retrieved January 29, 2018, from https://www.merriam-webster.com/dictionary/geodesy

National Coordination Office. (2017a). *Control Segment*. Retrieved February 2, 2018, from https://www.gps.gov/systems/gps/control/

National Coordination Office. (2017b). *Space Segment.* Retrieved February 2, 2018, from https://www.gps.gov/systems/gps/space/

Nohlen, U., & Petschek, P. (2014). *Grading and 3D Machine Control Systems: In Grading, LandscapingSMART, 3D Machine Control Systems, Stormwater Management* (2nd ed., pp. 201–211). Basel: Birkhäuser Verlag GmbH.

Peab. (2018). *Exempel på vad du kan jobba med.* Retrieved April 26, 2018, from http://www.peab.se/jobba-utvecklas/jobba-i-peab/vara-medarbetare-berattar/ex-pa-yrkesroller/

Riksterminalbanken. (2017). *Inmätning.* Retrieved March 28, 2018, from http://www.rikstermbanken.se/ts/visaTermpost.html?id=135364

Samuel A berg. (2011). *BYT 16, Geodesi och mätningsteknik.* Lärnö AB.

Schofield, W., & Breach, M. (2007). *Engineering Surveying* (Sixth edit). Oxford: Elsevier Ltd.

Sitech. (2018a). *Maskinstyrning, GCS900 3D GRÄVMASKINER.* Retrieved February 21, 2018, from http://www.sitechsolutions.com/se/products/maskinstyrning/gravmaskin/gcs900-3d-gravmaskiner/#information

Sitech. (2018b). *Total Station.* Retrieved May 14, 2018, from http://www.sitechsolutions.com/products/site-positioning-systems/total-station/

Svensk Byggtjänst. (2017a). *AMA Anläggning 17. Allmän material- och arbetsbeskrivning för anläggningsarbeten*. Stockholm: Svensk Byggtjänst.

Svensk Byggtjänst. (2017b). *Byggbranschen och digitalisering*, 1–62. Retrieved April 17, 2018 from http://info.byggtjanst.se/rs/626-CSV-637/images/d5_digtaliseringsundersokning.pdf

Svensk Byggtjänst. (2017c). *RA Anläggning 17. Råd och anvisningar till AMA Anläggning 17*. Stockholm: Svensk Byggtjänst.

Svensson, P. (2015). *Kvalitativ och kvantitativ undersökningsmetodik*. Retrieved April 9 , 2018 from https://student.portal.chalmers.se/sv/chalmersstudier/programinformation/maskinteknik/kandidatarbete/Documents/20150225 Vetenskapsmetodik förel 2 PS.pdf

Swedish Standards Institute. (2016). *Teknisk specifikation,SIS-TS 21143:2016, Byggmätning – Geodetisk mätning, beräkning och redovisning av byggnadsverk och infrastruktur* (Edition 5). Stockholm: SIS Förlag AB.

Swepos. (2018). *Klassificering och utrustning.* Retrieved February 26, 2018, from https://swepos.lantmateriet.se/swepos/stationer/klassochutrustning.aspx

Topcon. (2016). *GT Series, Robotic Total Station*. Retrieved May 4, 2018 from https://www.topconpositioning.com/total-station-solutions/robotic-total-stations/gt-series

Trimble. (2012). *Användarhandbok, Trimble ® GCS900 Grade Control System för Grävmaskiner* (12.20, Rev). Dayton: Trimble Engineering and Construction Division. Retrieved March 8, 2018 from http://www.sitechsolutions.com/wp-content/uploads/2014/10/GCS900_V1220B_Hex_OpMan_SWE.pdf

Trimble. (2014). *Maskinstyrningssystem*. Raunheim: Trimble Navigation Limited. Retrieved from http://www.sitechsolutions.com/wp-content/uploads/2014/10/022482-2511C-12-SE_GCS900_BRO_0314_LR_0.pdf

University of New Brunswick. (2018). *What is Geodesy and Geomatics?* Retrieved April 27, 2018, from http://www2.unb.ca/gge/AllAboutGGE/Glossary.html

Uren, J., & Price, B. (2010). *Surveying for Engineers* (Fifth Edit). London: Palgrave.

Walker, J., & Awange, J. L. (2018). *Surveying for Civil and Mine Engineers*. Cham: Springer International Publishing AG.

Figure references

Figure 4.
Müller, F.C. (2014). *# Total Station on tripod* [Online Image]. Retrieved from https://commons.wikimedia.org/wiki/File:Trimble_Total_Station_DR_200_02_(fcm).jpg

Figure 5.
Lantmäteriet. (2018) *Schematic figure of absolute positioning*. [Online Image] Retrieved from https://www.lantmateriet.se/sv/Kartor-och-geografisk-information/GPS-och-geodetisk-matning/GPS-och-satellitpositionering/Metoder-for-GNSS-matning/Absolut-och-relativ-positionering/

Figure 6.
Lantmäteriet (2018) *Schematic figure of relative positioning* [Online Image] Retrieved from https://www.lantmateriet.se/sv/Kartor-och-geografisk-information/GPS-och-geodetisk-matning/GPS-och-satellitpositionering/Metoder-for-GNSS-matning/Absolut-och-relativ-positionering

Figure 7.
Swepos (2018) *Illustration of the current densification of the SWEPOS network in Sweden.* Reprinted with permission.

Figure. 8
Igorevich, S.I. (2009) *Schematic figure of the components in a one-dimensional machine guidance system.* [Online Image] Retrieved from https://commons.wikimedia.org/wiki/File:Excavator-1.gif

Figure 9.
Igorevich, S.I. (2009) *Schematic figure of the components in a two-dimensional machine guidance system.* [Online Image] Retrieved from https://commons.wikimedia.org/wiki/File:Excavator-1.gif

Figure 10.
Igorevich, S.I. (2009) *Schematic figure of the components in a three-dimensional machine guidance system.* [Online Image] Retrieved from https://commons.wikimedia.org/wiki/File:Excavator-1.gif

Figure 12.
Lantmäteriet (2018) *Location of Gråbo, marked with a black cross.* [Online Image] Retrieved from https://kso.etjanster.lantmateriet.se/

Figure 13.
Lerum Kommun (n.d) *Schematic figure of the 11 planned plots near Oljebergsvägen in Gråbo.*

15 Appendences

Appendix A – Interview templates:

Interview template – Surveyor

Date of interview:..

Name:...

Company:...

Introduction:

Presentation of the aim of the master thesis

The aim of the interview

Background information of the interviewee:

What is your background?

Education?

Previous jobs?

Surveying in general:

1. What instruments are mainly used for manual surveying today?
2. When is manual surveying used today?
3. How have surveyors’ profession changed with the development of machine guidance systems?

Machine guidance systems:

4. Which system is the most common system for machine guidance today?
5. What is the accuracy of the different systems?
6. Is the accuracy of the systems enough to perform all measurements on a construction site?
7. When can machine guidance systems not be used?
8. When using the systems on a project, are control measurements performed by a surveyor?
9. How much time do a surveyor spend on a project using machine guidance, compared to a project with manual surveying?
10. Who produces the files or models that are needed for machine guidance systems?
11. Who has the responsibility if something goes wrong? For example, if the terrain model is incorrect, or the guidance system is uncalibrated and the machine operator excavate wrong?

Other questions:

12. Other thoughts on the topic?

Interview template – Company developing machine guidance systems

Date of interview:..…………………………………………….

Name:.………………………………………………………

Company:…………………………………………………

Introduction:

Presentation of the aim of the master thesis

The aim of the interview

Background information of the interviewee:

What is your background?

Education?

Previous jobs?

Machine guidance systems:

1. What machine guidance systems exist today?
2. Which systems is the most common system today?
3. What is the accuracy of the different systems?
4. What advantages and disadvantages does the systems have against each other?
5. For what can a three-dimensional system be used for if used fully?
6. When can machine guidance systems not be used?
7. How will the systems develop in the future?
8. How will the systems be affected by the development of Galileo?
9. When is it profitable to use machine guidance systems?

Other questions:

10. Other thoughts on the topic?

Interview template – Project planner

Date of interview:.………………………………………….

Name:.……………………………………………………

Company:…………………………………………………

Introduction:

Presentation of the aim of the master thesis

The aim of the interview

Background information of the interviewee:

What is your background?

Education?

Previous jobs?

Indata to machine guidance systems:

1. What is the process when creating traditional drawing and three-dimensional models?
2. From a time and cost perspective, does the creation of terrain models require more resources?
3. Who orders the three-dimensional models, the client of construction or the contractor?
4. Can you se a pattern in what kind or what sizes of projects three-dimensional models are used in?
5. What requirements are set on terrain models? (Content, accuracy, coding, quality control)
6. Who has the responsibility if the contractor has followed the model and errors occur due to that the model is wrong?
7. What benefits and disadvantages can you se with using three-dimensional models compared to using traditional two-dimensional drawings?

Other questions:

8. Other thoughts on the topic?

Interview template – Site manager

Date of interview:.………………………………………….

Name:.……………………………………………………

Company:…………………………………………………

Introduction:

Presentation of the aim of the master thesis

The aim of the interview

Background information of the interviewee:

What is your background?

Education?

Previous jobs?

How long have you been using machine guidance systems?

Machine guidance systems:

1. How do you use machine guidance systems on projects today?
2. What machine guidance systems are you using?
3. When can machine guidance systems not be used? When is manual surveying needed, why?
4. What advantages and disadvantages can you se with using machine guidance systems?
5. Is it common that the client requires that machine guidance systems are used in projects?
6. What requirements on accuracy does different objects have on ground construction projects?
7. How would you like to use machine guidance systems in the future?

Other questions:

8. Other thoughts on the topic?

Interview template – Machine operator of machine guidance system

Date of interview:..…………………………………………….

Name:..………………………………………………………

Company:……………………………………………………

Introduction:

Presentation of the aim of the master thesis

The aim of the interview

Background information of the interviewee:

What is your background?

Education?

How long have you been working as a machine operator?

How long have you been using machine guidance systems?

Have you been on a course or had other educations in machine guidance systems?

Machine guidance systems:

13. How are machine guidance systems used today?
14. Which machine guidance systems have you used?
15. Have you used excavators without machine guidance systems on projects? How was it?
16. What is important to remember when using machine guidance systems?
17. What is the most common errors or problems that occur when using the systems?
18. What are the advantages and limitations or the systems?
19. Development potential, what things can be improved?
20. What surveying tasks do you believe you can perform yourself?
21. What surveying tasks do you believe a surveyor should do?

Other questions:

Other thoughts on the topic?

Interview template – Corporate Adviser on Insurances

Date of interview:……………………………………………….

Name:……………………………………………………………

Company:…………………………………………………………

Introduction:

Presentation of the aim of the master thesis

The aim of the interview

Background information of the interviewee:

What is your background?

Machine guidance systems:

1. What insurances are needed by a company rending out construction machines and machine operators?
2. What insurances are needed by surveyors that perform setting out, measure in and production of construction drawings or models?
3. If a machine operator performs setting out and measure in tasks with a machine guidance system is additional insurances needed?