MOBILE MAPPING FOR THE REDUCTION OF CO_2 EMISSIONS, ADDITIONAL PURPOSES AND IMPACT IN THE GEODESY, BUILDING AND CIVIL ENGINEERING INDUSTRIES

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Colophon

This document comprises the final report of the Bachelor Thesis for completion of the Bachelor Civil Engineering at the University of Twente.

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PREFACE

Before you lies the final report of the bachelor thesis ‘Mobile Mapping for the reduction of CO_2 emission and additional purposes in the Geodesy, Building and Civil Engineering industries. The research is commissioned by LBA Groep to fulfil my Civil Engineering bachelor at the University of Twente. The research was carried out from April to July 2020.

Global warming is a major challenge nowadays, and all companies will have to contribute to reducing CO_2 emissions in order to diminish temperature increase. Sustainability and technological innovations are subjects that have always inspired me. This research contributes to the aim of reducing CO_2 emissions in the respective industries through Mobile Mapping. Thereby, the market chain is involved to test and assess the initiative to implement MM in the industries to reduce CO_2 emissions to increase the impact.

Due to the global pandemic of COVID-19, the bachelor thesis was, unlike theses from past years, conducted from home. Therefore, the experience of carrying out a research within a company has been lacking. Since the whole industry was forced to work from home, issues in communication, data gathering, and interviews arose. Fortunately, the research could be completed thanks to everyone involved in the process that showed great resilience and involvement in these difficult and strange times.

In particular, I would like to thank my supervisors, Rolands Kromanis and René de Boer, who guided and supported me through the process and from whom I learned a lot. Also a big thank you to all respondents of the interviews and questions I had during my research. Finally, I would like to thank my parents and friends for being supportive and helpful throughout the process.

Please enjoy reading my thesis,

Rens Ampting

Groenlo, June 19, 2020

EXECUTIVE SUMMARY

The building and construction sectors together account for 39% of the global CO_2 emissions (UN Environment and International Energy Agency, 2017). Thereby, transport accounts for almost a quarter of the total greenhouse gas (GHG) emissions in the EU, where road transport is responsible for 70% of the transport emissions. The Netherlands has set the goal to reduce GHG emissions with 49% by 2030. This results in a demand to reduce CO_2 emissions for companies. LBA Groep came with the initiative to implement new techniques like a Mobile Mapping System (MMS), a scanner that dynamically measures the environment, for the reduction of CO_2 emissions. This raises the question: What impact does Mobile Mapping (MM) have on CO_2 emissions in the Geodesy, Building and Civil Engineering industries and what other purposes does MM have that might have an impact as well? This research assesses the initiative to implement MM as a mean to reduce CO_2 emissions and replace traditional working methods (TWM) in the respective industries. In this context, the TWM is defined as the way work is currently carried out without implementing new technologies.

Based on a literature review and a desk research within LBA Groep, an understanding of MM is created, and applications and challenges are defined. Besides, semi-structured interviews were performed with two employees of LBA Groep to get an understanding to what criteria certain projects must comply to be carried out with MM. The criteria resulted in a selection of 14 projects. These are assessed on their CO_2 emissions using the TWM and by applying MM, whereafter the two methods are compared. The assessment is performed using quantitative data analyses and establishing a method to estimate the emissions. To test whether MM could have an impact industry wide, a water Authority and several contractors are interviewed to give their view on implementing MM and provide insights on the applications in their expertise.

In this research, 14 projects are evaluated. Data analyses reveals that emissions could be reduced by 44 up to 72% depending by implementing MM. Emissions are primarily caused by travel movements of projects. However, projects performed with the TWM with a low return rate experience an increase in emissions when carried out with MM. In order to reduce CO_2 emissions, travel movements should be decrease. The possibilities of MM vary from asset management to dike measuring. The market chain shows interest in using MM causing an enlarged impact of MM in the industries. The growing interest in technical innovations is important for MM to flourish. However, some parties do not see the benefits yet. This research also contributes to LBA Groep's goal to stay certificated at level 4 on the CO_2PL. Further research is needed to look at the economic feasibility of implementing MM at a large scale and what is needed to execute certain survey methods with MM.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ABBREVIATIONS

MM	Mobile Mapping
MMS	Mobile Mapping System
GHG	Greenhouse Gas
CO_2PL	CO_2 Performance Ladder (CO_2 Prestatieladder – NL)
EU	European Union
SKAO	Climate Friendly Procurement & Entrepreneurship Foundation (Stichting Klimaatvriendelijk Aanbesteden & Ondernemen - NL)
TWM	Traditional Working Method

CHAPTER 1 – INTRODUCTION

The aim of this research is to assess the initiative of using MM instead of the TWM in relation to CO_2 emission, and how MM could be beneficial for LBA Groep regarding applications in the Geodesy, Building and Civil engineering industries. This chapter reveals the motivation for this research, whereafter some key background knowledge is provided. The company, LBA Groep, is introduced and the concept of MM is explained. The CO_2 Performance Ladder (CO_2PL) is shortly introduced as well relating to LBA Groep and their initiative. The problem statement introduces, the problems encountered before starting this research, as well as the research questions. The relevance of this research explains the contribution of this research. The introduction is finalised with the scope of the study in which the main research techniques are introduced accompanied by a brief description of the structure and content of the report.

1.1 Motivation

The temperature of the world is evidently rising. Over the years 1901-2016, the global average temperature has experienced an increase of about 1.0°C (U.S. Global Change Research Program, 2017). The temperature is expected to rise with another 5°C by 2100, if no major reductions in GHG emissions are realised. Only with significant reductions in emissions the temperature rise could be constrained to 2°C or less (U.S. Global Change Research Program, 2017).

Hence, the European Union (EU), among the other Parties involved, have come to the Paris Agreement in 2015. This agreement comprises a framework to limit global warming to well below 2°C and preferably to 1.5°C. In order to reach these ambitious goals, the EU has set the objective to be climate-neutral by 2050, by having an economy with net-zero GHG emissions. One of the target the EU has set on a shorter term is to reduce GHG emissions with 40% by 2030 relating to the emissions in 1990 (European Union, 2020).

The building and construction sectors together account for 39% of the global CO_2 emissions (UN Environment and International Energy Agency, 2017). Thereby, transport accounts for almost a quarter of the total GHG emissions in the EU, where road transport is responsible for 70% of the transport emissions. The EU set the objective that by 2050 the GHG emissions from transport have to be reduced by 60%. One of the optimising strategies is the use of digital mobility solutions to improve efficiency and make transport more safe (European Commission, 2016).

The Netherlands, as Member State of the EU, was required to develop a strategy until 2030. The Netherlands have set the goal to reduce GHG emissions with 49% by 2030. In the Netherlands as well, transport accounts for one quarter of the CO_2 emissions (Ministry of Economic Affairs and Climate Policy, 2019).

This goal of reducing GHG emissions with 49% by 2030, comes with several initiatives throughout the Netherlands, like the CO_2 Performance Ladder (CO_2PL). The main goal of the performance ladder is for companies to have a substantial contribution to CO_2 reduction and to gain insights on implementing new innovations in projects. The CO_2PL is designed for companies to map and decrease their emission and to become aware of how their projects are carried out (SKAO, 2015).

LBA Groep is involved in the CO_2PL and has introduced a sector initiative to reduce CO_2 emissions. The initiative is aimed at modern applications during Geodesy, Building and Civil engineering projects that could lead to CO_2 reduction (LBA Groep, 2019). One of the modern applications that is proposed is MM to replace the TWM.

1.2 Background

1.2.1 LBA Groep and Mobile Mapping

LBA Groep is a company that operates in the Geodesy, Building and Civil Engineering industries. With their new system, the Leica Pegasus: Two Ultimate, they are able to carry out MM-services. The MMS is attached to a large van or a quad. MM is a method that dynamically measures the environment producing 360-degree images and point clouds. The data is stored in the MMS and can be extracted on the computer for analyses and visualisations. The MM-services provide the opportunity to replace some of the traditional work for LBA Groep. These TWMs demand activities that are often performed manually or semi-automatic with more human interference, in which mistakes and accidents are more likely to occur. Thereby, it requires visits and returning to the project site. LBA Groep submitted a sector initiative on the CO_2PL to reduce CO_2 emissions by implementing MM in the industries.

1.2.2 The CO_2 Performance Ladder

Climate Friendly Procurement & Entrepreneurship Foundation (SKAO) controls and develops the CO_2PL. The CO_2PL discriminates five certification levels on the ladder. This is visualized in figure 1. These levels indicate a company's maturity regarding their energy and carbon management, where the fifth level is the highest (Rietbergen, et al., 2016). The first 3 levels focus on the CO_2 reduction within their own organisation. Level 4 focusses on internal as well as external CO_2 reduction, e.g. reduction in the chain and having a contribution to innovation (SKAO, 2017). With level 5 the company shows that they achieved their goals and that they are able to innovate within the supply chain.

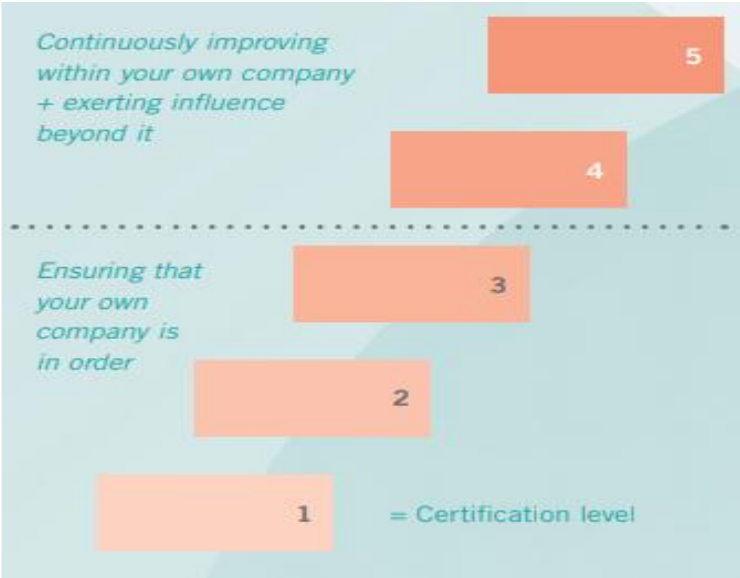

Figure 1 - The certification levels on the ladder (SKAO, 2017)

When clients release a project on the market, they could award the project with use of the CO_2PL. Companies participating in the CO_2PL are granted a percentual fictive advantage on the registration fees costs depending on their certificate level on the CO_2PL. The hight of the fictive advantage is predetermined in the client's contract, and depends on the level of a company on the CO_2PL (SKAO, 2015). For instance, assumed the percentual fictive advantage is 10% on the offer for a company that is listed on level 5. Now, two companies submit an offer on a project that makes use of the granting system based on the CO_2PL. The first company offers 10 million and is listed at level 5, the second company offers 9.5 million and not listed on the CO_2PL at all. Based on the offer, the contract will be granted to the first company, since a fictive advantage of 10% will bring the first company's offer down to a fictive offer of 9 million, which is lower than the second company.

In order to assess the CO_2-emission, CO_2PL makes use of three scopes, which are visualised in figure 2. Scope 1 represents the direct emission of the company, e.g. the company's vehicles emissions and installations. Scope 2 aims at the indirect CO_2-emission of the company, such as business travel and purchased electricity. Scope 3 emissions comprise the upstream and downstream emissions indirectly produced by the company's activities. These are emissions from sources which are not owned by the company. Mapping scope 3 is necessary for obtaining a level 4 and 5 on the CO_2PL.

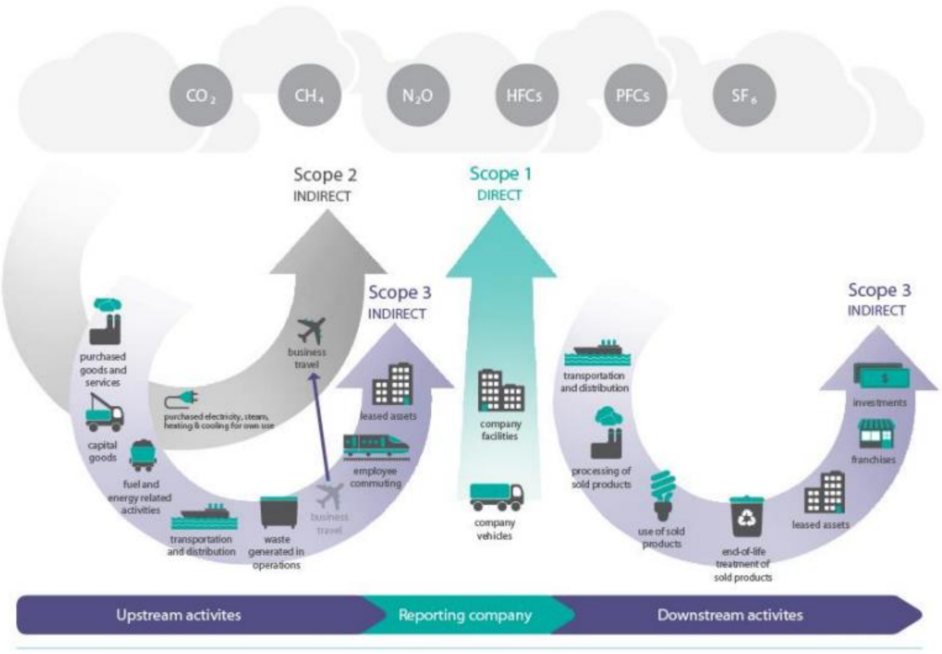

Figure 2 - CO2PL scope diagram (SKAO, 2015)

Several studies have been carried out on the impacts of the CO_2PL. According to Blok and Rietbergen (2013), it could have a substantial contribution to climate targets in the Netherlands. They estimate an annual projected CO_2 emission reduction of 0.8 to 1.5%. Another study evaluates the impacts of the CO_2PL on the improvement of energy and carbon management in construction and civil engineering companies (Rietbergen, et al., 2016). Interviews were conducted at a randomly selected sample of the target population of 25 companies, as well as a descriptive analysis of energy efficiency and CO_2 emission measures and a quantitative analysis. Rietbergen et al. (2016) found that it is very likely, despite the uncertainties, that an estimated annual CO_2 emission rate of 1.0-1.6 % per year could be assigned to the CO_2PL. Additionally, Rietbergen et al. (2016) concluded that, driven by the fictive advantage in contract awarding, the CO_2 emission reduction within construction and civil engineering firms is most likely achieved, because of the CO_2PL.

1.2.3 LBA Groep's Initiative

LBA Groep wants to stay certificated at level 4 on the CO_2PL. They are listed as a small company regarding CO_2 emission (DEKRA Certification B.V., 2019). This certificate was granted after LBA Groep did a chain analysis in scope 3 (LBA Groep, 2018). In this analysis they identified possibilities to reduce CO_2 emission. LBA Groep also set a goal for CO_2 emission. By 2022 they want to have a 5% reduction of CO_2 emission per employee in living and work mobility. In order to achieve this goal, they set some measures; provide information to create more awareness, stimulate employees to travel by bike, stimulate carpooling and to offer the possibility to work at home. Their recent sector initiative includes implementing MM for the reduction of CO_2 emissions.

1.3 Problem Statement

Due to global warming, governments make effort to reduce GHG emissions by setting objectives and creating frameworks. Building and construction industries contribute to 39% of the CO_2 emissions globally. The EU has set a goal to have a net-zero GHG emission economy. In order to achieve this, several national and international initiatives are introduced. In the Netherlands one of the main initiatives for companies is the CO_2PL. A framework in which companies keep track of their CO_2 emissions and trying to reduce this, within their own company with their incentives and the industries they work in.

Over the past few years, LBA Groep noticed that they and their clients are becoming more aware of the necessity to reduce CO_2 emission and to be sustainable (LBA Groep, 2019). There is a growing demand from the market and governmental institutions to reduce emissions on the accepted work. The first problem that occurs is:

There is a growing demand, without definite guidelines, for the reduction of CO_2 for companies like LBA Groep in the Geodesy, Building and Civil Engineering sector.

LBA Groep have achieved a level 4 on the CO_2PL. To maintain level 4, they should conduct a research within the scope of CO_2 reduction inside their company, which has an impact outside the company as well. They are looking for new working methods, with implementation of new technologies, to reduce CO_2 emission in the field of Geodesy, Building and Civil Engineering. MM is introduced to reduce CO_2 emissions. However, there are uncertainties about the effectiveness of this implementation and to what extend does it have an impact on CO_2 emissions for the company. This results in the second statement:

It is unclear to what extend MM has an impact on CO_2 emissions for LBA Groep.

In addition to replacement of TWMs and the influence on CO_2 emission, LBA Groep recognises their MMS is not running every working day. They are interested in the different techniques MM has to offer and how they could implement their system on a larger scale that might reduce CO_2 emissions industry wide. The third problem statement is then:

There is no clear overview on what additional MM applications are available and whether the initiative to use MM could have an impact industry wide.

The objective of this research is to create an understanding and assess the impact of MM on CO_2 emissions compared to the TWMs and to scrutinise what other purposes of the MMS could be implemented for LBA Groep to offer more services and achieve emission reduction in the industries. This results in the following main research question with corresponding sub-questions:

What impact does MM have on CO_2 emissions in the Geodesy, Building and Civil Engineering industries and what other purposes does MM have that might have an impact as well?

Sub-Questions:

1. *What techniques does LBA Groep's MMS consist of and what projects are already carried out with MM?*

2. *Which projects carried out in the past, that used TWMs, could have been replaced with MM?*

3. *What were the CO_2 emissions for the selected projects that were carried out with the TWM?*

4. *What would have been the CO_2 emission for the selected projects when MM was used and how do the outcomes relate to the evaluation performed in sub-question 3?*

5. *How could MM serve a bigger purpose for LBA Groep and the Geodesy, Building and Civil Engineering industries and how does the market reflect on this?*

1.4 Relevance

As mentioned in the introduction, global warming is a major issue nowadays and becomes more important by the time. Therefore, the Netherlands has set the objective to reduce GHG emissions with 49% by 2030. Companies are becoming more aware of the CO_2 emissions they produce. The market and governments require companies to be aware of their emissions and to try reducing it. This research is useful for companies that are working in the Geodesy, Building and Civil engineering industry, and companies that still carry out TWMs, to gain insights in how they could have an impact in reducing CO_2 emissions. Obviously, MM is not the only way to possibly reduce emissions. However, possible reduction methods could be deduced from this research. Thereby, MM applications are broadly analysed in this research. This could create insights in what other purposes MM has to offer next to the work that is already carried out by the company. This research is particularly relevant for LBA Groep since their initiative to reduce CO_2 emissions with MM is assessed. Thereby, they gain insights in the purposes their MMS has to offer for the industries they work in.

1.5 Scope of the study

A literature and desk research are conducted to define possible purposes for the MMS. Regarding the assessment of the impact of MM to CO_2 emissions, both a quantitative and qualitative analysis method is applied. A qualitative method is done by conducting semi-structured interviews with employees of LBA Groep and institutes in the market. A quantitative method is used to analyse data from projects that were carried out with the TWM resulting in CO_2 emissions that are compared to the situation where MM is used. The report is structured as follows. Chapter 2 includes a literature review on the MM concept, applications and challenges that are experienced in the industries where MM is used. The research types that are mentioned before, are extensively discussed in the methodology in Chapter 3. The methodology serves as a roadmap, provides a relationship model on the methods used and describes how the research is conducted. Chapter 4 comprises the results of this research. The results are subdivided into four categories; (i) the applications and challenges of MM, (ii) the selection of the 14 projects that are evaluated, (iii) an assessment and comparison of the CO_2 emissions for projects based on the TWM and MM, and (iv) the involvement and view on the MM initiative by the market chain resulting from interviews with contractors and a water Authority. The results are followed by the discussion, conclusion and recommendation, and future research suggestions.

CHAPTER 2 – LITERATURE REVIEW

In this section the existing literature on MM is discussed. This partly answers sub-question 1 for the understanding of the different techniques and applications of MM. The reader gets a deeper understanding of the concept of MM and the applications it has to offer according to the literature. Thereby, other forms of MM, like indoor and aerial, are briefly discussed and compared to terrestrial MM.

2.1 General concept

MM is a widely used technique in Geodesy, Building and Civil Engineering and is becoming more and more important. There is a growing demand for 3D mapping of cities and roads. MM is also used for road management, maintenance, and asset management (Lemmens, 2017). Tapken (2018), shows there is a growing interest in MM over the past view years. According to the study, the market of MM is expected to experience an annual growth of 21.3% on average up to 2023. Online services such as Google Street View, as well as the need for better georeferencing of object and spatial planning, have led to this increase in popularity of MM technologies (Vallet, et al., 2016).

2.2 The Mobile Mapping System

New technological developments come with the rise in demand and popularity of MM. In 2018 Leica Geosystems introduced the Leica Pegasus: Two Ultimate, the terrestrial MMS that LBA Groep is using. Terrestrial MM is a form of MM that is carried out relating to the surface. Leica states that this product enables companies to offer the best solutions in the market for infrastructure, planning and resource management projects (Leica Geosystems AG, 2018). The MMS makes use of four cameras in total. Two fish-eye cameras mounted back to back result in a 360-degree 24 MP image that is calibrated to a digital point cloud that can be colorized. Two 12 MP cameras comprises the 24 MP panoramic camera system. Additionally, the MMS has options to expand, with portals for thermal, sonar and ground penetration sensors as well as a pavement camera for precise capture along the road or in a tunnel (Leica Geosystems, 2018). The MMS consists of two sub-systems. One that measures the external and absolute position of the system using a Global Navigation Satellite System (GNSS). This is important for the coordinate system to be in the right place. The second measures the environment and thus the internal and relative accuracy of the system, using an Internal Measuring Unit (IMU) and Distance Measurement Indicator (DMI) (Mattheuwsen, et al., 2019).

2.3 Terrestrial MM

A Case study in London enlightens some of the features of the MMS. The study was performed with the Leica Pegasus Two Ultimate and carried out for the AppyParking app. This app enables users to see available parking areas, that are nearest and cheapest, accompanied by their characteristics, within in the city After 100 days of surveying, all parking zones across 19 London boroughs and five cities, that includes 6.500-line km, were captured. The system captured 1 million points of data per second and extracted 27 features per controlled parking zone. The survey found a relative and absolute accuracy better than 1.5 and 4 centimetres, respectively. Conclusively, it is stated that the average survey time is reduced by 80% compared to traditional survey methods (Lemmens, 2019). A comparison done by Leica Geosystems (2016), between the traditional survey methods and the use of reveals that costs are 3.9 times lower, the delivery time is 2.6 times faster and mobile data surveying requires 5.8 times less time spend in the field. MM could be applied in many management, construction, and maintenance projects in e.g. infrastructure, to make them more cost, time, and resource efficient.

Sairam, et al. (2016), suggests that infrastructure projects are made up of three phases: design and planning, construction, and maintenance. It is stated that maintenance involves the most time and costs and mentions the importance of accurate data collection. The article describes several extractions, such as automatic road marking extraction, road sign extraction and extraction of other assets like poles with use of an MMS. Tradition survey methods involves field data collection, that is converted into a CAD format. This involves multiple processing steps and is difficult to automate within an organization. Sairam, et al. (2016), also mentions some advantages of using an MMS instead. The initial costs of a MMS turns out to be optimally advantageous compared to the recurring costs of man power that is needed for the traditional survey methods, less nuisance to other traffic, safety for surveyors and data reviewing assessments at the office are some of the advantages mentioned. However, a major drawback described is the processing of the amount of data that is gathered, which could be overcome by data management techniques and automated extractions of assets. There is still a challenge for companies that use MMSs to store and process the huge volume of data captured to achieve the appropriate results (Holland, et al., 2016; Vallet, et al., 2016).

Yan, et al. (2016), addresses the issue of asset management and the challenge to maintain and update the latest highway or road inventory, which are vital for safety of road infrastructure. MM is able to fulfil these tasks to provide Mobile LiDAR data and point clouds for the automatic analysis and classification of objects along the road (Nebiker, 2017). Wu, et al. (2019), proposed a method in which point clouds retrieved from the MMS is used to extract and analyse potholes in the road. With a mean size accuracy of 1.5-2.7 cm they have shown that point clouds could be really useful for road management and surveying. Safety evaluations can be performed for different road lanes. Compared to the traditional methods for assessing potholes, the method described in the article has a higher identification rate and encounter less misclassifications. Road management and emergency management will benefit from this method as it is safer, faster, and more accurate than traditional methods. Other applications, mentioned in several articles, for MM on the road are identification and classification of light poles or pole-like objects ((Yan, et al., 2017) (Yan, et al., 2015)), the automatic extraction and reconstruction of road features such as markings using LiDAR data and point clouds ((Ma, et al., 2017) (Guo, et al., 2015) (Prochazka, et al., 2018)) and the classification of asphalt and stone pavement and road segments (Diaz-Vilarino, et al., 2015).

Puente, et al. (2013), describe the importance of a good visual environment in tunnels that is provided by the luminaries. Maintenance and quality monitoring of these luminaries should ensure safety and driving comfort. The article describes a method, to detect luminaries inside tunnels with use of a colorized point cloud resulting from a MM System. This method reduces survey time and minimizes the potential safety risks compared to traditional tunnel surveys. It has a virtual accuracy of 100 per cent and is able to see pattern in the lightning system and therefore able to detect broken or turned off luminaries. The survey should be performed in a dark environment where the luminaries are switched on to see the contrast. The method could therefore also be applied for street lamps in urban areas, which is also scrutinized by researchers from the Department of Built Environment from the Aalto University in Finland and the Finnish Geospatial Research Institute (Vaaja, et al., 2018). Continuousness performance of the survey which results in covering a larger area and the fact that data from the MMS is georeferenced and can be integrated into geo-information data for GIS are some of the advantages of using a MMS rather than the conventional stationary method to measure the luminance on the road (Vaaja, et al., 2018).

Apart from road management and maintenance purposes, as described above, MM is used in a much more diverse context. Lehtomäki, et al. (2019), proposed a method using mobile laser scanning for the extraction of power lines that resulted into an extraction precision of above 93%. Furthermore, in the Netherlands, a survey pilot, performed by Kempkes Landmeten in cooperation with water Authority Rivierenland, reveals it is possible to conduct dike surveys using an MMS. The article describes the survey of a 19 km trajectory dike in the Netherlands using the Leica Pegasus Two that was installed on either a car or a quad. It is also possible to mount the MMS on a boat to measure the dikes or embarkment. Traditional surveys would have taken months, while this survey was performed within a couple days. Parts that were not covered in the scan, where still surveyed with the traditional survey method or a static scanner. The surveying method with MM "has proven to be more flexible, safe, faster and scalable" (Kijzerwaard, 2017).

2.4 Aerial and Indoor MM

Besides a terrestrial MMS like the Leica Pegasus: Two Ultimate, it is also possible to use MM as an aerial service, using a drone for e.g. large area surveys, or indoor MM by using a backpack or hand-held system for architectural purposes for example (Campi, et al., 2018).

Campi, et al. (2018), published a paper that is presenting results of MMSs used for architectural surveys carried out both indoor and outdoor. The article made a comparison between indoor static and indoor dynamic surveying. The negative effects of using dynamic rather than static is shadows or variability in illumination. The positive effects are the more rapid acquisition. The article shows a case study where acquisition time is reduced by 80% or more. Time is also reduced during data processing, since dynamic surveys do not require assembly, opposed to the several scans when using static scanning. According to Leica Geosystems AG (2017), that supplies MM backpacks, the relative accuracy lies between 2 to 3 cm for outdoor and indoor purposes. The absolute position accuracy outdoor is 5 cm.

Goncalves, et al. (2018), address the need for replacement of classical survey methods of coastal management since they are very costly and labour-intensive. The article compares the use of airborne and terrestrial surveying for coastal management and monitoring in cases studies carried out along the North-Portuguese Atlantic coast. Three types of airborne photography surveying (plane, fixed-wing UAV, and multi-rotor UAV), an airborne LiDAR and a terrestrial MM system are compared. They concluded that the terrestrial MMS provides better accuracy on the ground, is easy to put into operation and deployable in almost any weather condition. However, the use of a terrestrial MM is limited for areas that are poorly accessible. UAVs like the drones were most restricted by weather conditions, such as wind speed and rain. The same goes for the Areal LiDAR and survey systems. However, UAVs were easier deployable and less invasive than terrestrial systems, but both are suite for small scale surveying with high precision. Obviously, plane surveying is more adequate for covering vaster areas at a lower accuracy.

2.5 Literature conclusions

The literature review provides a deeper understanding of the concept of MM and the possibilities the system offers to solve certain problems or make projects more efficient. Smart city applications, tunnel maintenance, light detection, road inventories and asset management, road conditions, power line mapping and coastal and dike management applications are discussed. Furthermore, the different MM techniques, indoor, aerial, and terrestrial are mentioned and compared.

Smart city applications are mentions like the AppyParking app in Londen. A project in which time is reduced by 80% compared to the traditional survey method. Research by Leica Geosystems also revealed a decrease of 3.9 times on costs, a 2.6 times faster delivery time and 5.8 times less time spend in the field. Also, maintenance of infrastructure projects is considered to involve the most time and costs in the traditional way, and difficult to automate within an organisation. It is vital for the safety of road infrastructure. According to the research, MM turns out to be optimally advantageous compared to recurring costs of manpower, causes less nuisance to other traffic, offers more safety for surveyors, and tend to be more accurate than the TWM. Coastal management is very labour-intensive and costly. MM is researched to be applied in coastal management to reduce this. Also indoor MM is tested and tend to reduce acquisition time by 80%, whereby relative and absolute accuracies are obtained of 2 cm - 3 cm and 5 cm, respectively.

However, there are some major challenges to overcome as well, of which data management might be the most important one. The huge amount of data captured by the MMS requires a lot of processing time. In addition, by digitalising the survey process through MM, manpower outside is less needed, but these employees are replaced by people that carry out data science and are able to process and analyse the data from the MMS. Terrestrial MM seems not ideal for poorly accessible areas, while on the other hand, this could be overcome by using aerial MM techniques. In addition, shadows and variation in illumination still tends to be an issue as well.

CHAPTER 3 – METHODOLOGY

This chapter provides an elaboration on the methods used in this research. The literature review that is carried out is important for understanding the system and lies the foundation of this research. Within LBA Groep a desk research is carried out which is compared to the literature research to define applications and challenges of MM. Thereafter, interviews with two employees are carried out to extract criteria to select projects, that are carried out in the past, which are evaluated. These qualitative methods are key for understanding MM in relation to LBA Groep. A quantitative data analysis method is applied for analysing the projects on their CO_2 emissions by using the TWM and MM. The two methods for carrying out projects are then compared to assess the impact of MM on CO_2 emissions on respective projects. In order to test whether the initiative to use MM could have a market wide impact, semi-structured interviews are carried out with several institutes representing the market. Figure 3 presents a relationship model of this research revealing the interrelatedness of the methods explained above. Upcoming sections break down the methods.

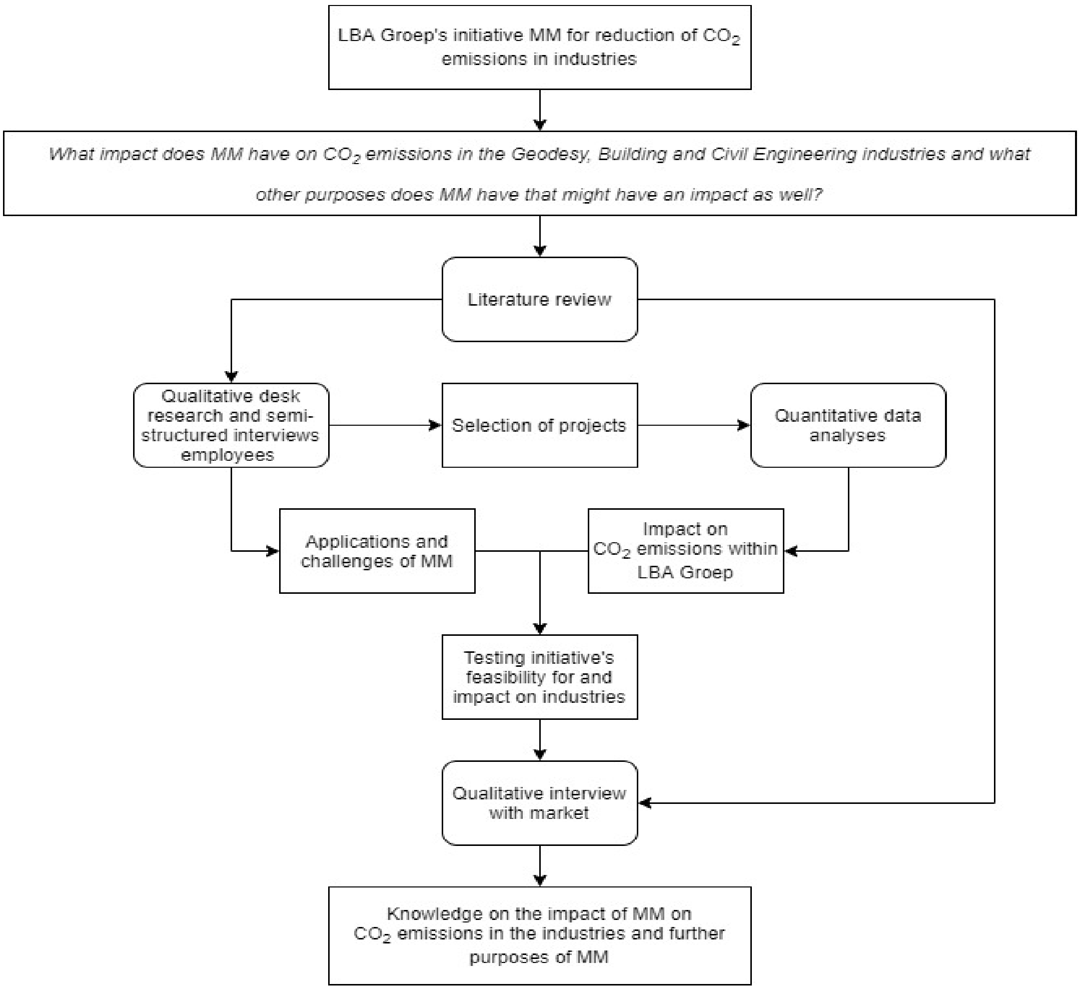

Figure 3 – Relationship model of research methods used

3.1 Identifying applications and challenges

This section explains the methods used to get a deeper understanding of the MMS and to find out what techniques, applications, and challenges there are concerning MM. The literature review already contributed some important scientific knowledge on these issues. Subsequently, a desk research is carried out within LBA Groep to extract information on their current status on MM. Employees are asked to provide information about challenges they encounter, and the work currently carried out with the MMS.

The information extracted from both the literature review and desk research, is compared to each other. This results in an overview of what applications of MM are not yet implemented within LBA Groep. Thereby, an overview of the advantages and major challenges that are experienced in the industry and within LBA Groep is provided.

3.2 Project selection

This section explains a qualitative method used for making an inventory of projects to be evaluated on their CO_2 emissions. Semi-structured interviews are carried out with T. Temminghoff and L. Koppelman. Through this interview, their experience is used to provide valuable information on how the data is retrieved from the MMS, how it is processed, what guidelines are used and what their expectations are. The interviews contribute to reaching the objective of getting an understanding of the criteria a project should meet to be replaced with MM, rather than the TWM.

3.2.1 Interview structure

A Semi-structured interview is selected to be most useful. There is incomplete knowledge about what is relevant to select the projects to be evaluated. However, the literature review and desk research already provided an understanding of MM and what might be relevant to ask. Therefore it is possible to have the subject and questions fixed to a certain extent in advance. While interviewing, a certain freedom is given to the interview which could lead to unexpected or valuable information for this research. Therefore, it is not desirable to have a fully structured interview, so a semi-structured interview is considered most preferable.

First, the subject is introduced whereafter the interviewees introduce themselves, their background, function, and experience with MM. Then, questions are asked concerning the differences between the TWM and MM relating time management, travel distance and data management and processing.

The interview is carried out with two people, the interviewer and interviewee, for the duration of 15-20 minutes. The interviews are conducted in Dutch. Considering the current situation with the COVID-19 crisis and measures from the government, interviews cannot be carried out in person. They are conducted through Microsoft Teams. LBA Groep uses this platform for communication within the company. The information is compared and evaluated in order to establish the criteria. These serve as an input to distil the projects that are carried out in the past from the database that are evaluated on their CO_2 emissions in sub-question 3 and 4.

In order to give the interviewees the possibility to provide an elaborate answer on their experience and affinity with MM, the questions are primarily open. With these questions, the most knowledge is extracted for reaching the objective. The English version interview schedule is stated in appendix I and served as a guideline through the interviews.

3.3 Estimating CO_2 emissions TWM

This section explains the methods used to estimate the actual CO_2 emissions for the 14 selected projects carried out with the TWM. The total emissions are defined by the (i) travel emissions and (ii) the CO_2 emissions due to use of equipment. The travel emissions form the direct emissions of the project relation to scope 1 on the CO_2PL. The energy use of equipment comprises scope 3, indirect emissions. Before thoroughly breaking down the different components, figure 4 provides a flowchart that illustrates the process of obtaining the total CO_2 emissions on the TWM.

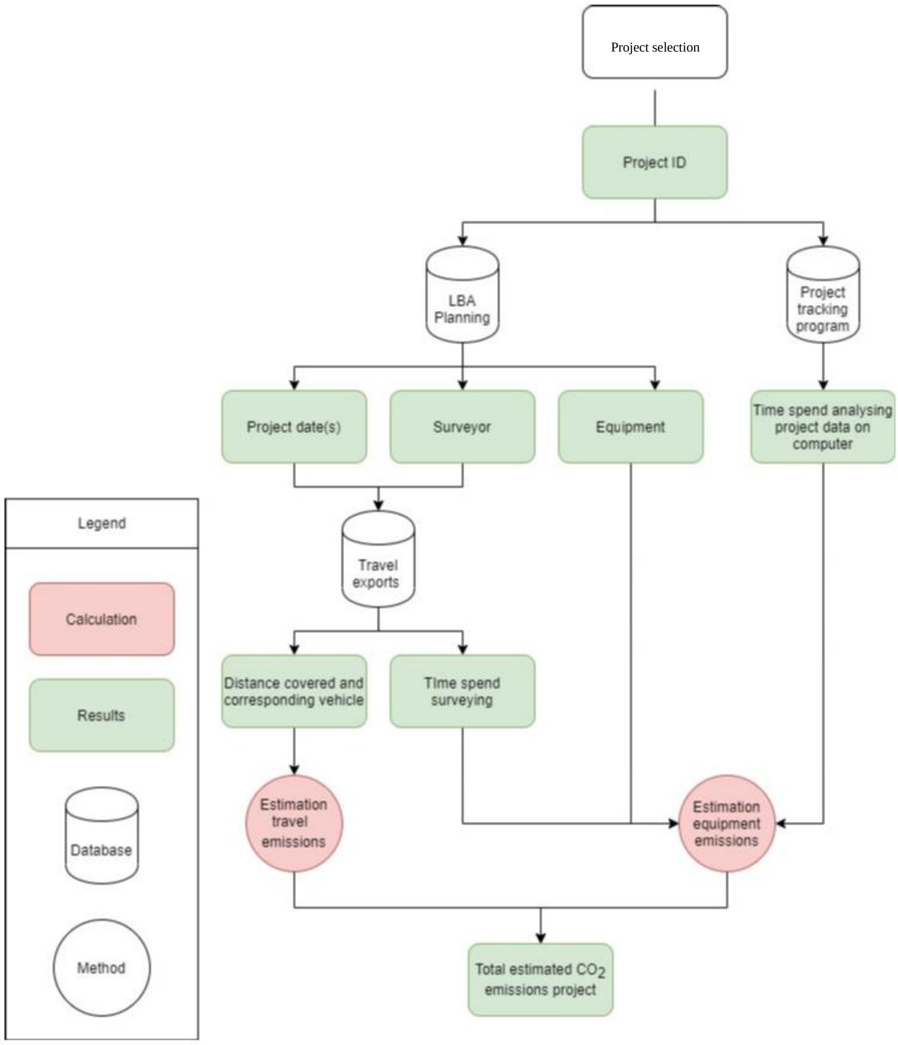

Figure 4 – Flowchart of process obtaining CO_2 emissions TWM

3.3.1 Travel emissions

Each project has an identical number, the Project ID. This ID is linked to the planning in the year the project was carried out. This reveals the date(s) on which work was carried out accompanied by the surveyor and equipment used for the projects. The travel exports from the company's vehicles, kept by the black box, is then used to identify the distance travelled for the project. Next to the distance driven, it also reveals the vehicle that was used providing the car's fuel consumption. The distance covered for the evaluated projects is determined by considering the following distances:

- The distance covered from the office or home to the evaluated project site
- The distance covered on site
- The additional distance covered or detour that was required for the evaluated project if more project sites were visited on the respective day.
- The distance covered from the evaluated project site to the office or home

3.3.2 Equipment emissions

Next to the emissions due to driving, it is important to evaluate the CO_2 emission due to electricity use by the equipment that was used when carrying out projects as well. The two main components for the TWM where electricity is used are; Analysing data in the office on the computer (1) and the traditional equipment used for surveying (2). As mentioned in the literature, MM data may require a longer processing time since a lot more data was captured in the field. This could have an impact on comparing the two methods on their CO_2 emission and are therefore considered in the evaluation process.

Appendix III provides the formulas used to the total emissions of the project's process carried out with the TWM.

3.4 Estimating CO_2 emissions MM

This section explains the methods used to estimate the CO_2 emissions if MM would have been used on the selected projects. It a roughly similar approach to the TWM. It is assumed that the same vehicle is used as the vehicle that is now used for MM purposes within LBA Groep. The maximum trajectory distance that could be covered for a project with a MM vehicle is around 60 kilometres per day on average (Koppelman, 2020). Therefore, the projects that are evaluated have a return rate of 1 for MM since the areas covered are smaller than the daily maximum. The return rate is the number of times a surveyor has to return to the project site for project related work. In addition, the trips made for projects are made from the company's office in Groenlo. Furthermore, the trajectory of the project site is mapped once or multiple times, dependent on the number of lanes, such that every aspect of the road is captured (Koppelman, 2020).

3.4.1 Travel emissions

To assess the travel emissions for MM, two scenarios are used. Scenario 1 describes a situation where projects are carried out each on a different day, where no proper planning is involved. The projects are carried out by driving to the site from the office in Groenlo, mapping the trajectory and driving back to the office. Scenario 2 would be a more optimal and realistic situation where proper planning is applied. Each day is scheduled depending on the maximum distance that could be covered and the period it was carried out (Koppelman, 2020). The period comprises 3 months, e.g. January-March. Since there are only two projects from 2018, these projects form one group as well. Projects carried out in the same period are put in sequence by applying the 'nearest intersection' route scheduling rule to find the most optimal route regarding travel distance (van der Heijden & van der Wegen, 2014).

3.4.2 Equipment emissions

Carrying out project with MM requires analyses as well as processing of data in the office (1) and makes use of the Leica Pegasus Two Ultimate as the surveying equipment (2) which are both assessed.

The emissions of travel and equipment used cover the total estimated CO_2 emission of a project carried out by MM. Details on the formulas used for calculations can be found in appendix IV. After evaluating both the TWM and the MM method, the two different ways are be compared.

3.5 Testing initiative on market

This section explains how the market is involved in the process through semi-interviews, which is vital for having an impact over a broader scope than just LBA Groep. The interviews are conducted with water Authority Rijn en IJssel, Anacon-Infra and Heijmans. They provide insights in what measures the institutes take to reduce CO_2 emissions in the market LBA Groep is represented, what could still be improved and what MM can contribute. This part of involving the chain is key on the CO_2PL, for MM to have a larger impact in the market (SKAO, 2017). In this way literature, where applications and challenges are found, data analyses on LBA Groep's projects and CO_2 emissions, and interviews are interrelated. First, the interviewees are introduced whereafter the structure of the interview addressed.

3.5.1 Interviewees

Water Authority Rijn en IJssel is a governmental institution. The interviewee is K. Margry, coordinator of geo-management. Anacon-Infra is a company working in roughly the same environment as LBA Groep, Doing Civil Engineering with a particular interest in infrastructure and environmental design. The interviewee is R. Mengerink, Director at Anacon-Infra with a background in Geodesy and Infrastructure. Heijmans is a large contractor in the Netherlands. The company has a lot of experience with sustainable measures in the work they carry out. P. Van Dueren den Hollander, project manager geodesy at Heijmans, is interviewed.

Before the interview was taken, the questions of the interview, and the research goal is sent to the interviewee. This enables the interviewee to prepare and think about the questions in advance to use the available time efficiently and to increase the knowledge output.

3.5.2 Interviewing structure

First, the subject is introduced whereafter the interviewees introduce themselves and the institution they work at. Then, questions are asked concerning the measures taken by their institution within their particular expertise to reduce CO_2 emissions and about what could be improved in the future. Whereafter, the questions become research specific regarding MM and CO_2 reduction, possible applications of MM to further contribute to reduction and involvement of the institutes with MM.

The interview is carried out with two people, the interviewer and interviewee, for the duration of 15-20 minutes. The interviews are conducted in Dutch. Considering the current situation with the COVID-19 crisis and measures from the government, interviews cannot be carried out in person. They are conducted through Microsoft Teams

In order to extract the most knowledge and to give the interviewee the opportunity to elaborate more on a question, open questions are used. The interviewing schedule is stated in appendix VIII and served as a guideline through the interviews.

3.6 Privacy and approval

During the first round of interviews, for project selection, no audio recording is made. The interviews were manually documented. The second round of interview, an audio recording is made on approval of the interviewee. With this audio recording a transcript is made that is solely used to summarise and extract information.

The transcripts are not published publicly, but could be made available on request, respecting the privacy of the interviewees. However, summaries are provided in Appendix II for the interviews concerning project selection, and appendix IX for interviews concerning involvement of the market chain. Before the interview was taken the interviewees were informed about how their data would be used, after which a confirmation is asked. The interviewee is also asked whether he/she wants to stay anonymous. After the interview, the transcripts are sent to the respective interviewees for verification purposes to avoid misconceptions.

CHAPTER 4 – RESULTS

This section comprises the results of this research. The results are divided into four parts. First, the applications and challenges of MM are discussed, which resulted from the literature review and desk research. Secondly, the results from the interviews for the selection of projects are revealed. A list is made on the projects that are evaluated. Thirdly, the results of the assessment and comparison of CO_2 emissions of the projects stated. Last but not least, are the outcomes of the interviews with the different institutes.

4.1 Applications and Challenges

This paragraph sets out the applications and challenges of MM by comparing literature with LBA Groep. On the basis of a desk research, insights are provided on the services LBA Groep offers by implementing their MMS along with the challenges that are experienced. Table 1 provides an overview comparing literature and results from the desk research.

Table 1 - Overview applications of MM based on literature and desk research

ID	Literature review	Desk research
1	Object extraction	Object extraction within obstacle-free zone along the road
2	Maintenance purposes; Road marking, road signs, and pole like object extraction	Extraction of markings, guardrail, and drive through hights
3	Automatic analyses and classification of objects	Road conditions
4	Road condition assessment, e.g. potholes	Construction of evaluation models of a road
5	Classification of asphalt, stone pavement and road segments	Visualisation purposes
6	Maintenance and quality on luminaries inside tunnels or urban areas	Assessment of tracings
7	Power line extraction	Depot measurements
8	Smart City applications, e.g. parking availability, and visualisations	-
9	Conducting dike surveys	-
10	Mobile Mapping from the water	-
11	Coastal management purposes	-
12	Indoor Mapping through a MM backpack	-
13	Aerial MM	-

Some similarities are indicated, like object, markings, and road condition extraction for maintenance purposes. LBA Groep's applications are found in the literature as well, excluding depot and tracings. The depots are measured by driving over the depot with a quad or van, after which the data is extracted and processed in the computer to determine the dimensions and volumes. The assessment of tracings (e.g. cables & pipes) are mapped with use of the pictures taken by the MMS. Literature reveals a wider variety of applications that are not yet known or carried out within LBA Groep. This includes classification of pavements, illumination condition testing and tunnel maintenance applications, power line or cable mapping, smart city applications such as parking availability, dike surveying and coastal management, as well as airborne and indoor MM applications.

In the literature review and desk research, challenges regarding MM are revealed. A list is provided to clearly mention the challenges currently faced by LBA Groep and literature:

1. Data storage and processing of huge volumes of data to achieve the appropriate results.
2. Terrestrial MM, such as the system of LBA Groep, are limited to areas that are poorly accessible.
3. Indoor MM is subject to shadows or variations in illumination.
4. Obtaining the proper absolute accuracy for certain measurements.
5. People tend to fall back into original habits, which makes the threshold of using MM high.
6. It is difficult to estimate what information should or should not be provided to the client and what data could be deleted or not.

Regarding the challenges by implementing MM, it produces a huge amount of data compared to the TWM. This is already a data storage challenge at the moment, not to mention future projects' data. There is the data directly from the MM system, and the adjusted data used for the analysis and evaluations. Deletion of certain data might bring some problems in the future. Additionally, there is the challenge of attaining the proper absolute accuracy for certain measurements. There are some organisational challenges mentioned as well. People tend to fall back into their original habits, rather than practicing with MM. The market has to be convinced of the fact that MM could really have a contribution to the current work. Since a lot of data is retrieved from the MM survey, it is difficult to estimate what information should or should not be provided for the client. Sometimes it is not clear what the clients wants to do with the information and what quality the client expects. Therefore it is more likely that there is an excess or deficit of information for the client. Also, it is not clear what could be done with the huge amount of data next to the original goal. The interview with Koppelman (2020) revealed that setting boundaries for quality and information is essential for time and cost efficiency on the accepted work (Koppelman, 2020). The recommendation provides advice on how to tackle these challenges

4.2 Selection of projects

This paragraph sets out the results from the company interviews. Criteria are established form the interviews whereafter 14 projects are selected that are evaluated criteria are established. For more information, the interview summaries are given in appendix II.

4.2.1 Criteria establishment

Both interviewees explain there are no really strict criteria for a project to be carried out with MM or not. The decision is primarily based on in what field the project carried out and experts' assumptions. To be able to select projects, the assumption that TWM projects with a trajectory length below 400m are not efficient enough to replace with MM since they could be carried out within one day with the TWM (Temminghoff, 2020). Trajectories larger than 400 meters, would be interesting for MM. Also, only projects with surface measurements are selected since LBA Groep is not able to carry out below surface measurements yet. Geodesy projects could almost all be replaced with MM since these are all measurements done at the surface with a quite long trajectory. Civil project could also be replaced if the trajectory is larger than approximately 400m. Projects carried out in the building industry require too precise measurements and are often performed with a static scanner. Therefore, the initial criteria established are.

- The trajectory of the TWM project is larger than 400 meters.
- The type of project is in the Geodesy or Civil Engineering department of LBA Groep.
- The projects should preferably have surface measurements only

To be able to select projects from the database, the criteria are based on assumptions derived from the interviewed employees and their experience. Therefore, this research creates insights into improving and optimising these initial criteria, based on the results.

4.2.2. Project selection

Projects that LBA Groep carried out in the past are stored in the database. The projects that satisfy the criteria are selected. The 14 projects that have been selected are shown in table 2. The project number is given as well as the project name accompanied by a description. Each project is assigned an identical ID from 1 to 14. The projects that are selected primarily concern the surveying of topography, situation, and heights measurement.

Table 2 - Projects selected for evaluation

ID	Project Number	Project Name	Description
1	10190098	Zutphen Herinrichting Kanonsdijk en Weg naar Voorst	Redesign of the road
2	10191445	V01-Groenlo revisie Borculoseweg	Surveying topography
3	10190154	V02-Huissen revitalisering Zilverkamp	Surveying topography of road
4	10190188	V00-Hengelo Winkelskamp	Surveying topography of ground
5	10190276	V02-Ede Veldhuizen	Measuring heights relative to NAP
6	10190300	Hendrik Ido Ambacht Beatrixsingel	Surveying situation and cadastral boundaries
7	10191114	Ede revisie Van der Hagenstraat	Surveying topography
8	10191146	Wageningen De Dreijen	Surveying situation and cadastral boundaries
9	10191678	Huissen Sportdreef	Surveying situation
10	10191897	Cuijk Snelfietsroute De Valuwe	-
11	10190095	Vorden Wildenborchseweg en Lochem Vordenseweg	Surveying plateaus
12	10190218	Doorwerth Bachlaan en Richtersweg	Surveying topography
13	10181565	Arnhem Roermondsplein	Surveying situation on surface
14	10180791	Lunteren herinrichting	Surveying topography

4.3 Evaluation CO_2 emissions

This paragraph elaborates on the assessment of the project's CO_2 emissions carried out with the TWM and with MM. This section is finalised with a comparison between the two methods.

4.3.1 Traditional Working Method

The results of the emissions of projects carried out with the TWM is visualised in figure 5. Appendix III and VI, show the formulas and results, respectively.

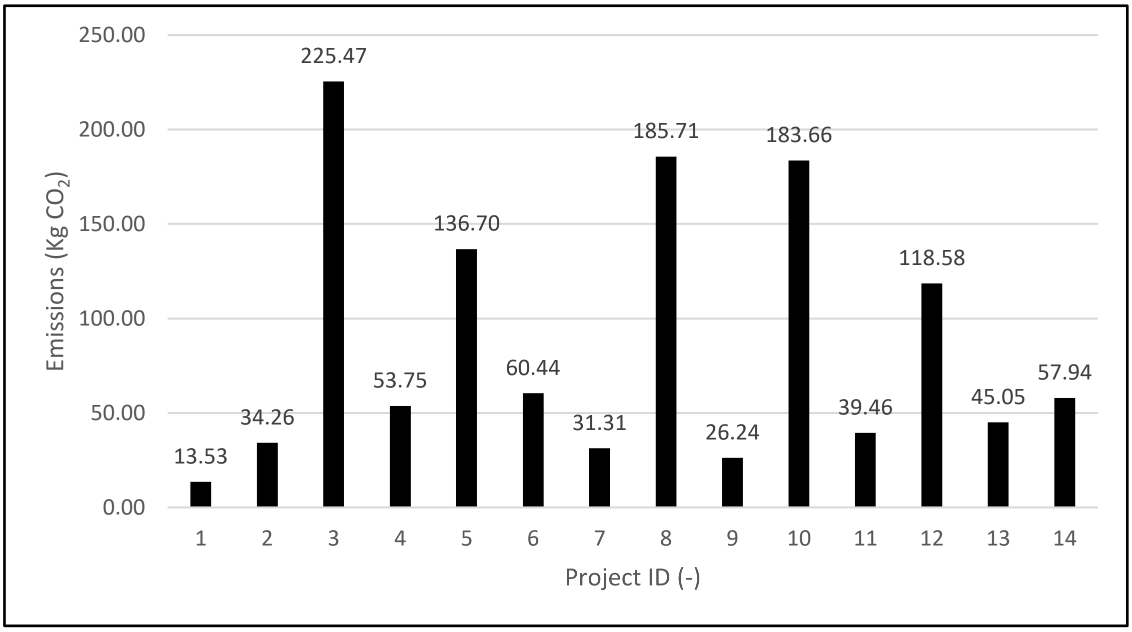

Figure 5 - Emissions of projects carried out with the TWM

The total CO_2 emission comes down to 1212.1 Kg CO_2 based on the 14 projects evaluated, with on average 86.58 Kg emitted per project. Project ID 3 has with a share of 18.6% the largest CO_2 emissions with 225.47 Kg and Project ID 1 the smallest share with 13.53 Kg CO_2 emissions. The emissions due to equipment use such as computers for processing and analyses and working equipment for surveying, is 2.32% of the total emission. The emission due to travel has by far the largest share of 97.68%.

Figure 6 represents a graph where a relation between the total emissions and the return rates of projects are compared concerning the 14 projects.

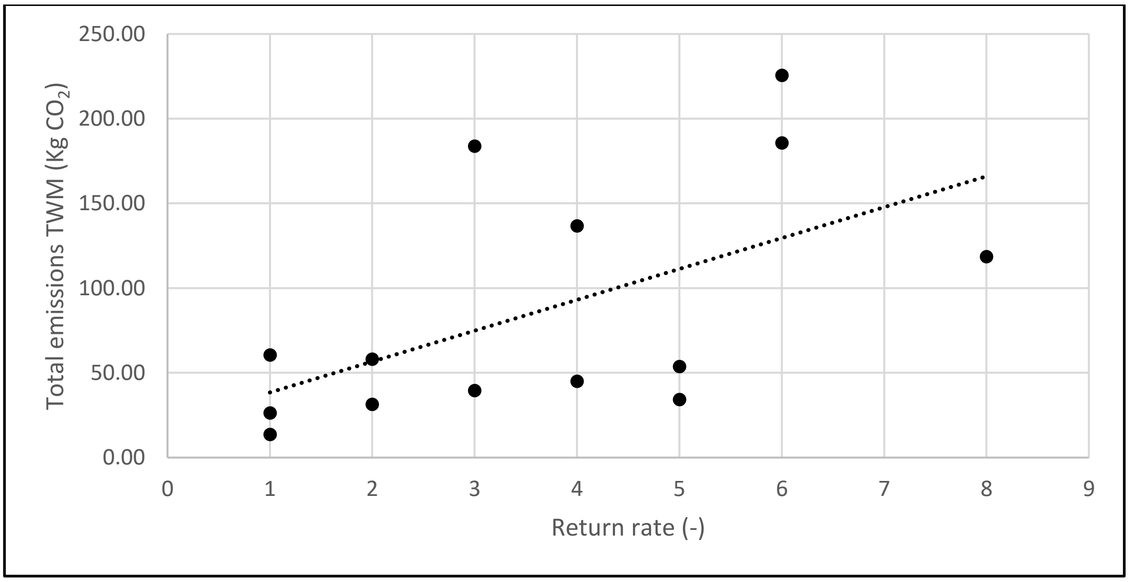

Figure 6 - Correlation between total emissions and return rate of the TWM

The graph suggests a positive correlation between the two, based on a linear relationship. So with an increasing return rate, the total emissions of a project rise. The project with the highest total emission has a return rate of 6, where on average the projects have a return rate of 3.64 times. This means 3.64 trips to the projects site for project related activities. Project ID 12 has the highest return rate of 8 and produced the 5th largest emissions with 118.58 Kg CO_2.

A comparison of the relation between the trajectory length and return rate is also made. This is visualised in figure 7.

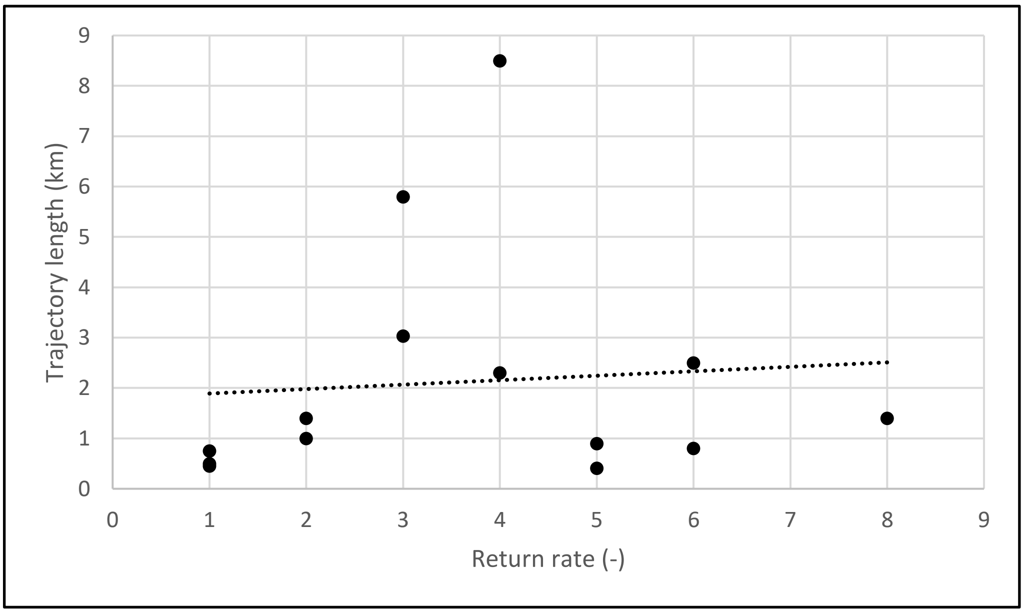

Figure 7 - Relation between trajectory length and return rate

Comparing the trajectory length with the return rate, the trajectory length slightly increased compared to an increasing return rate. However, the graph suggests there is no convincing correlation, based on a linear relationship. This is explained by the fact that the trajectory length does not indicate how much work is or the type of work that is carried out. Some projects with a small trajectory length require more work than projects with a large trajectory.

4.3.2 Mobile Mapping

As mentioned in the methodology, two scenarios are evaluated for the emissions due to travel and surveying with the MMS. Figure 7 visualises the emissions by implementing scenario 1, where projects are carried out each on a different day. The return rate of every project is 1. Appendix IV and VII show the formulas and results, respectively.

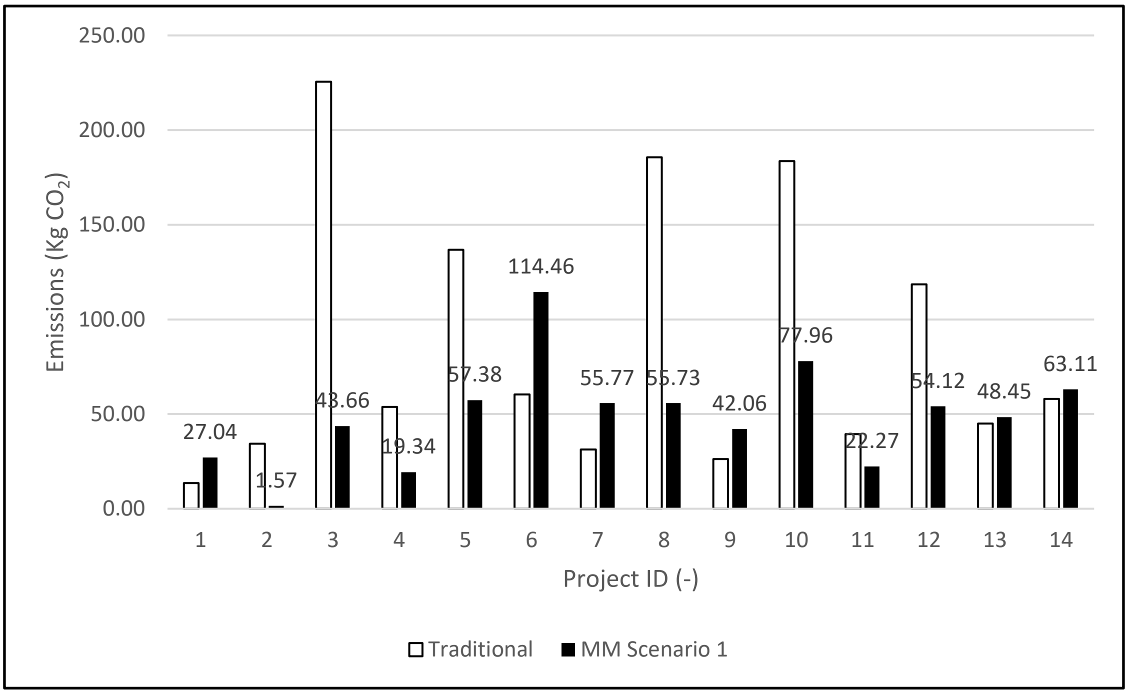

Figure 8 - Emissions of projects carried out with MM scenario 1

The total CO_2 emission comes down to 682.92 Kg based on 14 evaluated projects, with an average emission of 48.78 Kg CO_2. Project ID 6 has the largest share of 16.76% with 114.36 Kg CO_2 emission. The emissions due to equipment used is 1.03% whereas travel has the largest share of 98.97%. Some projects experience an increase in emissions. This is explained in section 4.4.3 that includes the comparison of the different methods.

For scenario 2, an approach where proper planning is used, four groups of projects are made to be carried out on the same day, based on the assumptions stated in paragraph 3.4. The groups of projects that are evaluated is given in table 3. Figure 7 visualises the total emissions per group by implementing scenario 2.

Table 3 - Groups of projects to be evaluated for scenario 2

Group ID	**Period**	**Project ID**
1	Jan-March 2019	1,3,4,5,6,11,12
2	Jul-Sep 2019	2, 7, 8
3	Oct-Dec 2019	9, 10
4	2018	13, 14

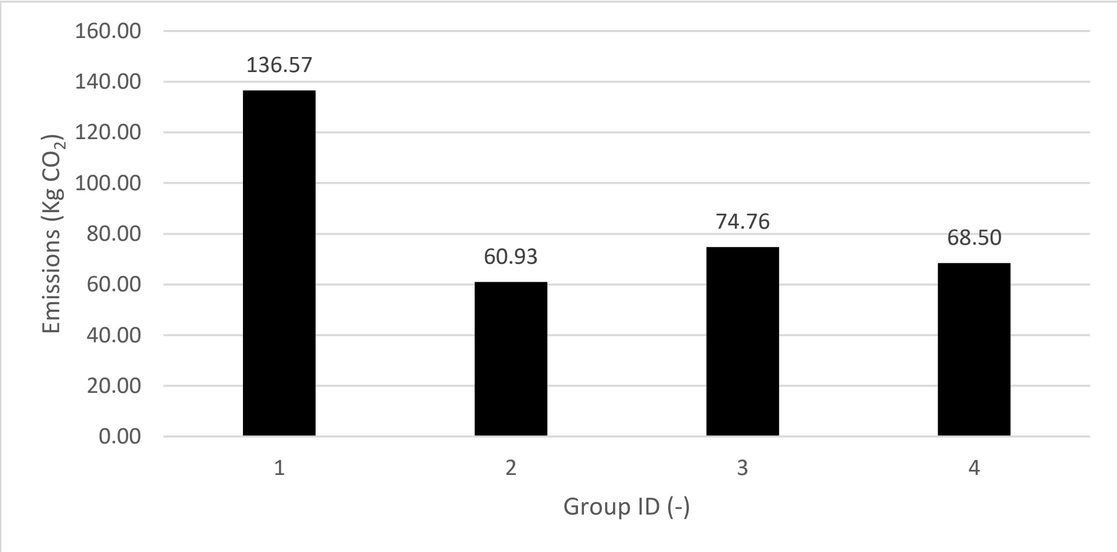

Figure 9 – Total emissions of projects carried out with MM scenario 2

The total emission comes down to 340.76 Kg based on 4 groups with in total 14 projects. The average is 24.34 Kg CO_2 per project. Group 1 has the largest share of 40.08% and an emission of 136.57 Kg CO_2 with 7 projects involved. Since 7 projects are carried out on the same day, the average emission is 19.51 Kg CO_2, which is lower than the overall project average. In group 2 the average emission of 37.38 Kg CO_2 and is a lot higher since only two projects are carried out on that day. The emissions due to electricity use, because of computers and equipment, is 2.07% of the total emission. The emission due to travel and trajectory survey has the largest contribution with 97.93%. Thereby, when implementing proper planning, vehicle movements are reduced, causing less depreciation and a longer lifespan of the company’s cars.

4.3.3 Comparison

Comparing the TWM and the MM method including the two scenarios covering the total emissions of the three methods used to estimate the project emissions.

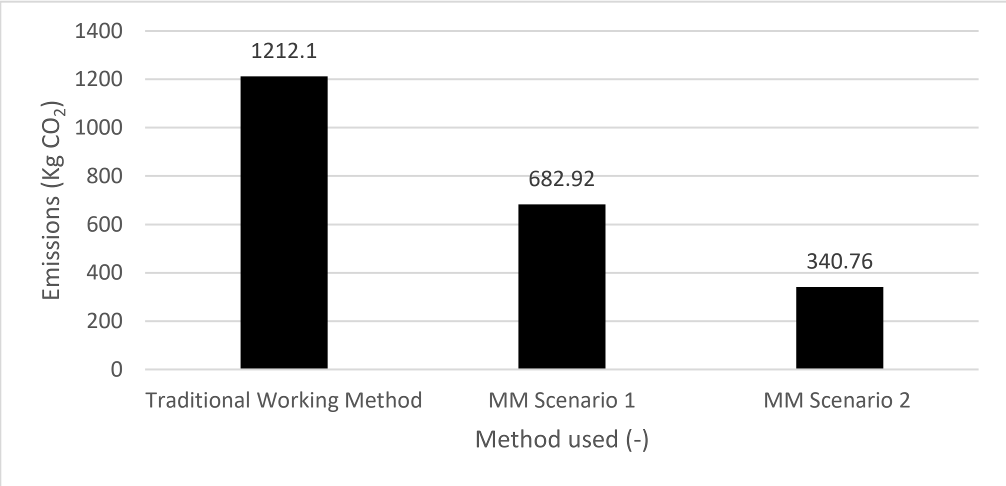

Figure 10 - Total emissions of the 3 methods

By implementing MM by using scenario 1, where projects are carried out separately, a reduction of 43.66% equal to 529.18 Kg CO_2 is realised compared to the TWM. By implementing MM using scenario 2 where proper planning and scheduling is applied, a reduction of 71.89% is realised, equal to 871.34 Kg CO_2, compared to the TWM. By implementing MM, the return rates have been diminished to 1. The correlations in figure 6, suggested that emissions are reduced with a reducing return rate. In general this is the case

In order to test this individually, the return rate of the TWM is related to whether reduction is realised by implementing MM in scenario 1. The return rate is sorted smallest to largest and compared.

Table 2 - TWM return rate compared to whether reduction has been realised

Return rate	1	1	1	2	2	3	3	4	4	5	5	6	6	8
Reduction?	No	No	No	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes

The table comparison suggests that for projects carried out with the TWM with a return rate of 2 or lower, no reduction realised. Projects with a return rate of 3 or higher, experience reduction, except for project ID 13. This is explained by the fact that this project has been carried out without making a detour on the day it was carried out with the traditional working method. The reason for this, is that the vehicle on which the MMS is attached, has a Since some projects have a low return rate, and the MM vehicle produces more emissions and is less sustainable. Therefore, the overall emissions on the project could rise for projects with a low return rate, which is recognised in figure 8. This is the case with project 1 for example. The TWM produced an emission of 13.52 Kg CO_2, whereas in scenario 1 the estimated emission is 26.76 Kg CO_2. Based on scenario 2, the average emission for this project is 19.41 Kg CO_2.

4.4 Impact of MM on the market

This section provides results on the interviews with the market and chain in which LBA Groep is represented. This would complete the cycle between literature, LBA Groep and the chain wherein applications, challenges, and having an impact on CO_2 emissions are tried to be related. The interviews resulted in six points of attention.

1. Digitalisation and new techniques are an important issue being addressed in the interviews. The water Authority are having a pilot where dynamic measuring is implemented in the mowing process of canals and rivers. This technique could also be applied by smart use of MM and making use of the environment. Anacon-Infra has digitalised their work and are working towards a fully 3D project preparation process, in which MM lies the foundation. Whereas, Heijmans digitalises their work through online platforms, and remotely controlling their machines. The interest in innovative techniques, lowering risk and digitalising is rising in the market.

2. Digitalisation and making use of MM also means using less manpower in field, and reduces people going outside for measurements. The water Authority does this by digitalising and dimensioning assets, reducing the number of visits to certain areas. P. van Dueren den Hollander (2020) also explains that with the right implementation of MM, projects become more risk averse and maintenance could be done more focussed on points were tolerances are not met.

3. A drawback from MM on the road is that certain areas cannot be accessed, explains K. Margry (2020). Outside of just road surveying there is still a lot to gain, especially when techniques are developed in which surveying through vegetation is possible.

4. Thereby, data management is still an issue explains P. van Dueren den Hollander (2020). Sharing huge amounts of data would slow down software and sometimes this means the same data is used on two different locations, which is a risk. Therefore, data is aimed to be store offline and locally to increase the processing speed and reduce risks. Solutions would

be online storage or working on huge amount of data in several phases, by vector tilling (van Dueren den Hollander, 2020).

5. From a market perspective, all three parties see potential for MM in the future, with the increasing need of data, risk management and 3D developments. However, R. Mengerink (2020) explains there is still a lot to be done, since municipalities are not aware of the benefits, and the threshold for using MM is still quite high, and suggests to stimulate MM by revealing it's capabilities and end products.

6. Thereby, it is noticed through the interviews that for clients, like municipalities and the water Authority, costs involved are still guiding for making the decision. Less attention is paid for the way how the overall process is carried out. This is also due to the fact that the advantages of MM are not yet recognised (Mengerink, 2020). This might still be an issue if MM wants to contribute more to the market and have an impact on CO_2 reduction.

DISCUSSION

The results indicate that MM has a reducing impact to CO_2 emissions overall given the 14 projects. The main contribution to the emissions is travel movements for a project. The way MM project are implemented is also important since a scheduled day requires less travel movement than a day where only one project is carried out. Regarding the implementations and reducing impact of MM, the chain analyses with different parties show there is an interest in MM and its applications. Margry (2020), from water Authority Rijn & IJssel suggests there is still a lot of reduction to be realised if techniques of the MMS are more sophisticated, such as scanning through vegetation. R. Mengerink (2020) suggests that MM should be stimulated within the market, especially regarding municipalities who are not yet familiar with the advantages and applications it offers. Van Dueren den Hollander (2020) explains Heijmans is digitalising a lot within his expertise and elaborates on the fact that MM could contribute to not only CO_2 emission reduction, but also safety, better risk management and less human interventions.

However, there are still uncertainties regarding MM implementations involving issues with data management. There is still a challenge for companies that use MMSs to store and process the huge volume of data captured to achieve the appropriate results (Holland, et al., 2016; Vallet, et al., 2016). Some applications of MM are not yet developed enough to be implemented by companies to be able to carry out projects with this technique. Looking at the reducing factor of MM towards CO_2 emissions, the return rate with the TWM is an important indicator. Contrary to the overall reduction result, results of individual projects show that for projects with a return rate of 2 and lower, no reduction in CO_2 emissions is realised. For project with a return rate is higher than two, there is a reduction in CO_2 emissions except for project ID 13. The increase in emissions is mainly impacted by the high vehicle's emission on which the MMS is constructed.

Criteria established in section 4.2 are primarily based on the expert experience and assumptions of the interviewed employees. These criteria should be improved based on the results. Therefore, based on using the same MM vehicle, projects with an expected return rate of 2 or lower with the TWM, should not be replaced with MM, or should be scheduled properly to avoid detours and CO_2 emissions.

The research provides insights, for LBA Groep as well as the industry, into the impact of MM on CO_2 reduction and what challenges are experienced and applications that are available. Quantitatively analysing LBA Groep's data on past projects carried out with the TWM contributes to a clear understanding of emissions that arise when carrying out a project and how MM relates to decreasing or even increasing CO_2 emissions.

The generalisability of the results is somehow limited to projects that are similar to the evaluated projects. It is beyond the scope of this study to conclude that every MM implementation results in a reduction of CO_2. However, one could infer that CO_2 is reduced overall if travel movements are diminished by implementing MM in projects. Thereby, some variables and assumptions, that were needed for calculations, like the time spend surveying with the MMS, are built upon the experiences of employees within LBA Groep. This could differ for other companies that implement MM as well. The applications found in the literature review and market should still be researched on their feasibility and the necessities needed for a company to be implemented like underwater surveying with use of echo loading (Margry, 2020). Further research should also consider the economic feasibility for a company to implement MM, and the challenge of how to deal with data management issues.

CONCLUSIONS

This research aimed to assess the initiative of LBA Groep on the impact of MM on CO_2 emissions in the Geodesy, Building and Civil Engineering industries and to identify further purposes of MM. Some interesting purposes of MM found through literature review and interviews are tunnel maintenance, cable mapping, coastal and dike management, and smart city applications. However, not all projects are replaceable the LBA's MMS, especially in the building industry and projects that require below surface measurements. Geodesy and Civil engineering projects are most suitable to be replaced with MM. 14 Projects are evaluated.

Based on both qualitative and quantitative analyses, through interviews and data analyses respectively, CO_2 emissions are reduced by roughly 44% to 72%, regarding the 14 projects, depending on whether proper planning is applied or not. The reduction is caused by a decrease in travel movements over the projects that are evaluated by implementing MM. However, projects with a return rate of 2 or lower, experience an increase of emissions, which is caused by the MM vehicle that is more polluting than the traditional survey vehicles of LBA Group. A positive correlation is identified over the 14 projects that suggests that the project emissions increase when the return rate to the project site increases with the TWM.

By interviewing several parties represented in the industries, digitalisation and technical innovation is a big trend, in which implementing MM is recognised and could have a substantial role. Implementing MM also causes less deploying of manpower infield, less human mistakes causing less returns, better risk management and more safety. Reduction the lead time between scans and 3D models, will increase the number of possibilities. Challenges, like data management, are issues that are also experienced in the market. Online platforms or use of vector tilling might help handling huge amounts of data. Additionally, the threshold of using MM is quite high and clients might not be aware of the benefits. Clients that offer projects are still more focussed on the solution and costs, rather than the process in which MM could be used.

While this research limits itself to finding new applications and assessing the impact on CO_2 emissions, additional research into the specific applications could provide insights into how MM should be implemented and what necessities are needed for certain applications. Thereby, researching economic feasibility and deployment of employees could provide insights into implementing MM in an efficient way and increasing the impact of it.

This research shows that MM could have a contribution to limiting the CO_2 emissions by effective implementations and by replacing the TWM. Further purposes of MM are defined and the view from the market is brought to light. LBA Groep are able to use this research to further contribute to the CO_2PL and maintain their certificate level 4.

RECOMMENDATION

With the implementation of MM, several challenges are listed in the results. The results and conclusions indicate a decrease in CO_2 emissions based on the projects that are evaluated, in which the return rate of projects is an important indicator. In addition, interviews with the different institutes in the market reveal important knowledge on what contribution MM could have in the industries. Based on the results and conclusions drawn from this research, recommendations are provided for LBA Groep. Nine suggestions are listed below:

1. Projects that are small scale or have a low return rate of 2 or lower with the TWM, should not be replaced with the current MM vehicle, when trying to achieve CO_2 reduction. Unless, the small projects are scheduled properly, or a more sustainable MM vehicle is used.
2. Return rates and thus travel movement, is the major contributor to CO_2 emissions. Reducing this by implementing MM on projects wherefor the TWM projects have a return rate higher than 2, results in deceasing CO_2 emissions.
3. Resulting from market interviews, it is recommended to stimulate MM through the market since the threshold to use MM is high. Making clients familiar with MM, introducing pilots, and revealing the end product could increase implementation throughout the market and reduce emissions.
4. Further research in data management is needed since this is a major issue. Online data storage could help and making use of vector tiling.
5. Clients are commonly more interested in costs than in the way work is carried out. This motivation should change. However, by trying to make the MM process as cost efficient as possible, impact of MM on reduction, and acceptance on tenders are more likely to occur.
6. Automate the process from scan to end product. By reducing the lead time, more possibilities occur.
7. Look into innovative techniques, like VR, AR, and remote control, which are trending. Leading the way in innovation and sustainability could benefit the company.
8. Further research is recommended on economic feasibility and on what necessities certain MM applications require.
9. It is recommended to further research the demand of MM and how it affects the company. Implementing MM could have an impact on traditional surveyors and increase the employment of indoor data processing.

These recommendations should help LBA Groep to generate more MM applications, reduce CO_2 emissions and for MM to have a larger impact industry wide.

REFERENCES

Campi, M. et al., 2018. Indoor and outdoor mobile mapping systems for architectural surveys. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Science,* Volume XLII-2, pp. 201-208.

Chainwise, 2020. *Chainwise LBA Groep.* [Online]
Available at: chainwise.nl
[Accessed May 2020].

CO2 emissiefactoren, 2020. *CO2 emissiefactoren.* [Online]
Available at: https://www.co2emissiefactoren.nl/lijst-emissiefactoren/
[Accessed 07 May 2020].

DEKRA Certification B.V., 2019. *CO2-bewust Certificaat, niveau 4,* Arnhem: Stinging Klimiaatvriendelijk Aanbesteden & Ondernemen.

Diaz-Vilarino, L. et al., 2015. Automatic classification of urban pavement using mobile LiDAR data and roughness descriptors. *Elsevier,* pp. 208-215.

European Commission, 2016. *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS, A European Strategy for Low-Emission Mobility,* Brussels: European Commission.

European Union, 2020. *ec.europa.eu.* [Online]
Available at: https://ec.europa.eu/clima/policies/strategies/2050_en
[Accessed May 2020].

Goncalves, J. A. et al., 2018. Three-dimensional data collection for coastal managment - efficiency and applicability of terrestrial and airborne methods. *International Journal of Remote Sensing,* 39(24), pp. 9380-9399.

Guo, J., Tsai, M.-J. & Han, J.-Y., 2015. Automatic reconstruction of road surface features by using terrestrial mobile lidar. *Eslevier,* pp. 165-175.

Holland, D. A., Pook, C., Capstick, D. & Hemmings, A., 2016. The topographic data deluge - Collecting and maintaining data in a 21st century mapping agency. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* Volume XLI-B4, pp. 727-731.

Kijzerwaard, A., 2017. Protecting the Netherlands agains floods with Mobile Mapping technology. *Geo Informatics.*

LBA Groep, 2018. *Ketenanalyse woon-werkverkeer, CO2-prestatieladder niveau 4,* s.l.: Stichting Klimaatvriendelijk Aanbesteden & Ondernemen.

LBA Groep, 2019. *Welke moderne toepassingen kunnen leiden tot CO2-reductie tijdens de uitvoering van de werkzaamheden in Geodesie, Bouwmaatvoer en Civiele techniek,* s.l.: Stichting Klimaatvriendelijk Aanbesteden & Ondernemen.

LBA Groep, 2020. *LBA en 3D scannen (Document).* Groenlo: LBA Groep.

Lehtomäki, M. et al., 2019. Power line mapping technique using all-terrain mobile laser scanning. *Elsevier*, pp. 1-16.

Leica Geosystems AG, 2009. *Leica TPS1200+ Series, High performance total station,* Heerbrugg: Leica Geosystems AG.

Leica Geosystems AG, 2015. *Leica Nova MS60, Data sheet,* Heerbrugg: Leica Geosystems AG.

Leica Geosystems AG, 2015. *Leica Viva TS16, Data sheet,* Heerbrugg: Leica Geosystems AG.

Leica Geosystems AG, 2016. *Leica Pegasus: Two, Mobile reality capture,* Switzerland: Leica Geosystems AG.

Leica Geosystems AG, 2016. *Leica Viva GS14, Data sheet,* Heerbrugg: Leica Geosystems AG.

Leica Geosystems AG, 2017. *Leica Pegasus: Backpack,* Heerbrugg: Leica Geosystems AG.

Leica Geosystems AG, 2018. *Leica Pegasus: Two Ultimate, Mobility reality capture,* Switzerland: Leica Geossytems AG.

Lemmens, M., 2017. Mobile Laser Scanning Point Clouds. *gim-international*, p. 4.

Lemmens, M., 2019. Smart parking; app based on mobile mapping point clouds and imagery. *Gim-international,* pp. 11-13.

Ma, H., Pei, Z., Wei, Z. & Zhong, R., 2017. Automatic extraction of road markings from mobile laser scanning data. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Science*, pp. 825-830.

Mattheuwsen, L., Bassier, M. & Vergauwen, M., 2019. Theoretical accuracy prediction and validation of low-end and high-end Mobile Mapping Systems in urban, residential and rural areas. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Science,* Volume XLII-2/W18, pp. 121-128.

Ministry of Economic Affairs and Climate Policy, 2019. *Integrated National Energy and Climate Plan, 2021-2030,* s.l.: Ministry of Economic Affairs and Climate Policy.

Nebiker, S., 2017. 3D Imagery for infrastructure management - Mobile Mapping meets the cloud. *ResearchGate*, pp. 1-6.

Otten, M., 't Hoen, M. & den Boer, E., 2015. *STREAM personenvervoer 2014, Study naar transportemissie van alle modaliteiten emissiekentallen 2011,* Delft: CE Delft.

Prochazka, D., Prochazkova, J. & Landa, J., 2018. Automatic lane marking extraction from point cloud into polygon map layer. *European Journal of Remote Sensing,* Volume 52, pp. 26-39.

Puente, I., González-Jorge, H., Martínez-Sánchez, J. & Arias, P., 2013. Automatic detection of road tunnel luminaires using a mobile LiDAR system. *Elsevier,* pp. 569-575.

Rietbergen, M. G., Opstelten, I. J. & Blok, K., 2016. Improving energy and carbon management in construction and civil engineering companies - evaluating the impacts of the CO2 Performance Ladder. *CrossMark,* pp. 55-79.

Sairam, N., Nagarajan, S. & Ornitz, S., 2016. Development of Mobile Mapping Systems for 3D road asset inventory. *MDPI*, pp. 1-19.

SKAO, 2015. *Handboek CO2-prestatieladder 3.0*, s.l.: SKAO.

SKAO, 2017. *Hoe maak je bebruik van de CO2-prestatie-ladder? Een praktische gids voor bedrijven,* s.l.: SKAO.

Tapken, P., 2018. Mobile Mapping Trends and Insights. *Geomares.*

U.S. Global Change Research Program, 2017. *Climate Science Special Report,* Washington: U.S. Global Change Research Program.

UN Environment and International Energy Agency, 2017. *Towards a zero-emission, efficient and resilient buildings and construction sector. Global Status Report 2017,* s.l.: UN.

Vaaja, M. T. et al., 2018. Mobile mapping of night-time road environment lighting conditions. *The Photogrammetric Journal of Finland,* 25(1), pp. 1-17.

Vallet, B., Mallet, C., Baghdadi, N. & Zribi, M., 2016. Urban Scene Analysis with Mobile Mapping Technology. In: *Land Surface Remote Sensing in Urban and Coastal Areas.* Oxford: Elsevier, pp. 63-100.

van der Heijden, M. C. & van der Wegen, L. L. M., 2014. Collegedictaat. In: *Ritplanning.* Enschede: University of Twente, pp. 13-18.

Windows, 2016. *Windows-helpdesk.* [Online]
Available at: https://www.windows-helpdesk.nl/stroomverbruik-computer/
[Accessed May 2020].

Wu, H. et al., 2019. Road pothole extraction and safety evaluation by integration of point cloud and images derived from mobile mapping sensors. *Elsevier*, pp. 1-11.

Yan, L. et al., 2017. Detection and classification of pole-like road objects from mobile LiDAR data in motorway environment. *Elsevier*, pp. 272-283.

Yan, W. Y., Morsy, S., Shaker, A. & Tulloch, M., 2015. Automatic extraction of highway light poles and towers from mobile LiDAR data. *Elsevier*, pp. 162-168.

LIST OF INTERVIEWEES

1. Koppelman, L. (2020, April 22). Criteria establishment project selection. Conducted through MS Teams
2. Margry, K. (2020, June 10). Involving the market chain. Conducted through MS Teams
3. Mengerink, R. (2020, June 15). Involving the market chain. Conducted through MS Teams
4. Temminghoff, T. (2020, April 23). Criteria establishment project selection. Conducted through MS Teams
5. Van Dueren den Hollander, P. (2020, June 16). Involving the market chain. Conducted through MS Teams

APPENDICES

I. Interview schedule (EN): Criteria establishment project selection

Bachelor thesis questionnaire 1

Instructions for the interviewers

- Ask all questions, do not skip any questions
- Keep the order as indicated
- Never to give own opinion

Respondent number	
Name interviewer	
Name interviewee	
Interview date	
Time	
Place	

Interview introduction

- Introduction interviewer
- Introduction of the subject
    - Mobile Mapping and criteria establishment for project selection
- Explanation what contribution the interviewee has to the research
- Explaining the types of questions
- Explain how the interview is processed: written report
- Duration of the interview: 10-15 minutes

Before we go into detail, I would like to ask about you:

1. What is your experience with MM and what is your function?

Now, I will be asking some specific opinion and experience questions regarding MM and the TWM

2. Could you tell something about time management with MM compared to the TWM?

3. What do you think about Cost effectiveness and the implementation of MM compared to TWMs?

4. What is the relation between the distance covered in a project and the decision on whether to use MM or the TWM?

5. What type of projects are really not replaceable with MM and what type of projects are, e.g. Geodesy or Civil projects?

6. Regarding data extracted from the MM System, is there a difference in processing and analysing data compared to the TWM?

7. Finally, what do you think of the outcome of this research relating to CO_2 emissions?

Closure:

- Do you have any other remarks regarding the subject of this interview that might be of value for my research?

- Thank the interviewee for his/her time and repeat what will happen with the data retrieved from the interview.

II. Interview summaries: Criteria establishment project selection

Note:

- The interviews have not been recorded. The interview was kept by manually tracking the important things.

- The transcripts are not publicly published due to privacy reasons but are available on request.

Respondent number	1/2
Name interviewer	L. Koppelman (R)
Name interviewee	Rens Ampting (I)
Interview date	22/04/2020
Place	MS Teams

According to Koppelman (2020), time is being used more efficiently when comparing the MM and TWMs. However, this lies more nuanced, since more qualitative data is produced in less time, but this data might not even be necessary and could have been achieved with the TWM as well. Furthermore, the data produced by the MMS contains much more information and is therefore more complex and requires more knowledge and processing time than the individual points measured with the TWM. Relatively seen, Koppelman believes that the overall process of MM projects is faster and more cost efficient. The technique of MM, which is actually always available, is replacing the more uncertain human interventions. Construction dimensioning is usually not among the MM projects. Its decision is primarily based on the expert's and experience consideration, weather conditions and expectation and demands from the customer. The fact that the company has an MMS, generates new projects in other markets that were not possible without the system. Koppelman mentioned a project where 600km of highway is mapped and extracted. This project would have never been done without the MMS. To compare, Koppelman mentioned that the highway was mapped in roughly 10 days driving over 4000km, whereas the TWM would require 60 days mapping, driving 12.000 km and roadblocks. Safety is therefore also an important consideration in doing a project with MM.

Respondent number	2/2
Name interviewer	T. Temminghoff (R)
Name interviewee	Rens Ampting (I)
Interview date	23/04/2020
Place	MS Teams

Temminghoff (2020) explained that the distance that has to be covered in a project is important for the decision to do something with MM or with TWMs. TWMs survey 400 meters per day on average, whereas a MM does several kilometres. For small projects it could still be beneficial to carry out with TWMs, since the survey time and processing time for MM takes quite long. On a certain point, the times consumed by MM and by the traditional way cross each other, from where it requires less time to carry a project out by using MM. Data retrieved by MM is a lot more informative and therefore the project that is delivered is more optimal, even if it requires more time. Large data files could have processing times of 12 hours or more. Temminghoff explained that MM is not used for construction dimensioning in the building industry, apart from visualisation purposes. It is primarily used for geodesy purposes and some civil engineering projects like road reconstruction if the trajectory is long enough. Regarding CO_2 emission, Temminghoff expects MM would have a reducing factor if the traditional surveyor had to return to the project area.

III. Calculations travel and equipment emissions TWM

Equation 1 shows the formula for calculating the project's estimated travel emission with TWMs (Pttsm). The actual distance (Da) made for the projects will be a summation the distances that were covered for the project. Furthermore, every vehicle has an average fuel consumption (Fa), expressed in L/100km, which are retrieved from the database. An overview of the average fuel consumption for each car per year was established for LBA Groep to give them an overview of the vehicle and employee fuel consumption. The CO_2 emission per litre fuel (Cf) will be the amount of kilograms CO_2 that is emitted per litre diesel, which is 3.23 Kg/L diesel (Otten, et al., 2015).

$$P_{ttsm} = \left(\frac{\mathrm{Da} * \mathrm{Fa}}{100}\right) * \mathrm{Cf} \tag{1}$$

Equation 2 shows the formula for calculating the project's CO_2 emission due to electricity use (Pa) for analysing data in the office (1). The time spend analysing for a project (Ta) is retrieved from the database LBA Groep uses to keep track of company processes (Chainwise, 2020). The average electricity use of the computers (Ec) will be the amount of KWh used for the average computer in the office in 1 hour, i.e. 0.2 KW (Windows, 2016). The CO_2 emission of 1 KWh 'grijze stroom' (Cg), a non-sustainable electricity source and used by LBA Groep, is 0.556 Kg CO2/KWh (CO2 emissiefactoren, 2020).

$$P_a = T_a * E_c * C_g \tag{2}$$

Equation 3 shows the formula for calculating the project's CO_2 emission due to electricity use for using traditional surveying equipment (Ptse) (2). The time spend surveying with the equipment (Ttse) is approached by analysing the time spend on the site by the surveyor retrieved from the black box exports. The electricity use of the equipment (Etse) is expressed in KWh and given in appendix V.

$$P_{tse} = T_{tse} * E_{tse} * C_g \tag{3}$$

Results are provided in Appendix VI.

IV. Calculations travel and equipment emissions MM

Equation 4 shows the formula for calculating the estimated travel emissions for the projects with MM (Ptmm). The total estimated driving distance (De) will be the distance from and to the project area plus the trajectory of the project area. The trajectory distance will be obtained by analysing the delivered work and extracting the distance. The average fuel consumption of the MM vehicle (Fa) over the year of 2019, is 10.36 L/100km. The CO_2 emission per litre diesel (Cf) will be 3.32 Kg CO_2 (Otten, et al., 2015).

$$P_{tMM} = \left(\frac{\mathrm{De}*\mathrm{Fa}}{100}\right) * \mathrm{Cf} \tag{4}$$

Equation 5 shows the formula for calculating the project's CO_2 emission due to electricity use for processing and analysing data in the office (Ppa). The time for processing the data (Tp) is estimated at 1 hour per 6 km trajectory (Koppelman, 2020). Processing data from the MMS is the extraction of datasets and determining the geographical locations. The end results are georeferenced pictures and information with which analysis is possible. The time spend analysing the data (Ta) is estimated at 8 hours for 6 km trajectory (Koppelman, 2020). The average electricity use of the computers (Ec) will be the amount of KWh used for the average computer in the office in 1 hour (Windows, 2016). The CO_2 emission of 1 KWh 'grijze stroom' (Cg), is 0.556 Kg CO2/KWh.

$$P_{pa} = (T_p + T_a) * E_c * C_g \tag{5}$$

Equation 6 shows the formula for calculating the project's CO_2 emission due to using the MMS (P_{MMS}) (2). The time surveying on a trajectory with the MMS (T_{MM}) is estimated that per hour a trajectory of 7.5 km is mapped (Koppelman, 2020). The electricity use of the MM equipment, the Leica Pegasus: Two Ultimate, (E_{MM}) is expressed in KWh and is given in appendix V. The CO_2 emission of 1 KWh 'grijze stroom' (Cg), is 0.556 Kg CO2/KWh.

$$P_{MMS} = T_{MM} * E_{MM} * C_g \tag{6}$$

Results are provided in Appendix VII.

V. Information sheet surveying equipment

Surveying system	Operation time (h)	Electricity Use (KW per hour use)	Source
Leica TS16	6.5	0.005	(Leica Geosystems AG, 2015)
Leica TPS 1203	6.5	0.007	(Leica Geosystems AG, 2009)
Leica MS60	8	0.004	(Leica Geosystems AG, 2015)
Leica GS14/GS15/GS16	8	0.002	(Leica Geosystems AG, 2016)
Leica Pegasus: Two Ultimate	11	0.244	(Leica Geosystems AG, 2018)

VI. Results CO_2 evaluation TWM

Table 3 - Project's emissions due to travel with TWM

ID	Project number	Return rate	Emission (kg CO2)	Share of total
1	10190098	1	8.84	0.75%
2	10191445	5	32.39	2.74%
3	10190154	6	220.31	18.61%
4	10190188	5	51.73	4.37%
5	10190276	4	134.47	11.36%
6	10190300	1	59.13	4.99%
7	10191114	2	28.98	2.45%
8	10191146	6	183.72	15.52%
9	10191678	1	25.83	2.18%
10	10191897	3	183.57	15.51%
11	10190095	3	38.22	3.23%
12	10190218	8	116.26	9.82%
13	10181565	4	43.96	3.71%
14	10180791	2	56.55	4.78%

Table 4 - Emissions due to equipment use and in-office analyses

ID	Project number	Ptse (Kg CO_2)	Pa (Kg CO_2)	Total (Kg CO2)
1	10190098	0.021	4.670	4.691
2	10191445	0.149	1.724	1.873
3	10190154	0.15	5.004	5.154
4	10190188	0.069	1.946	2.015
5	10190276	0.087	2.141	2.227
6	10190300	0.033	1.279	1.312
7	10191114	0.049	2.280	2.329
8	10191146	0.159	1.835	1.994
9	10191678	0.021	0.389	0.410
10	10191897	0.086	0.000	0.086
11	10190095	0.070	1.168	1.238
12	10190218	0.173	2.141	2.313
13	10181565	0.094	1.001	1.095
14	10180791	0.060	1.334	1.394

Table 5 - Total emissions for the TWM

ID	Travel emission (Kg CO_2)	Electricity emission (Kg CO_2)	Total emission (Kg CO_2)
1	8.843	4.691	13.534
2	32.390	1.873	34.263
3	220.312	5.154	225.466
4	51.732	2.015	53.747
5	134.471	2.227	136.698
6	59.132	1.312	60.443
7	28.977	2.329	31.306
8	183.716	1.994	185.710
9	25.829	0.410	26.239
10	183.575	0.086	183.661
11	38.224	1.238	39.462
12	116.263	2.313	118.576
13	43.959	1.095	45.054
14	56.545	1.394	57.939

VII. Results CO_2 evaluation MM

The results of the project's travel emissions for MM based on scenario 1 can be found in table 6.

Table 6 - Travel emissions MM scenario 1

ID	Project number	Date	Estimated Total distance (km)	Travel emission (Kg CO2)	Share
1	10190098	Jan-19	77.8	26.76	3.96%
2	10191445	Sept-Okt 2019	3.6	1.24	0.18%
3	10190154	Jan-May-Jul 2019	125.6	43.20	6.39%
4	10190188	Feb-Mar-May 2019	56.01	19.26	2.85%
5	10190276	Feb-Mar 2019	165.6	56.96	8.43%
6	10190300	Mar-19	332.5	114.36	16.92%
7	10191114	Jul-19	161.4	55.51	8.21%
8	10191146	Jul-Aug 2019	161.6	55.58	8.22%
9	10191678	Oct-19	122.05	41.98	6.21%
10	10191897	Nov-19	225.03	77.40	11.45%
11	10190095	Jan-19	58.5	20.12	2.98%
12	10190218	Feb-Mar 2019	156.6	53.86	7.97%
13	10181565	Okt-Nov 2018	136.3	46.88	6.94%
14	10180791	May-18	182.4	62.74	9.28%

As stated in the assumptions, the return rate is 1 for all projects since the total distance on site covered is manageable to carry out in one day. The results represent the emissions in scenario 1, where all projects are carried out on different days.

The results of the evaluation of the projects based on scenario 2 can be found in table 7.

Table 7 - Travel emissions MM scenario 2

Group ID	Period	Project ID	Total group distance (Km)	Travel emission (Kg CO2)
1	Jan-March 2019	1,3,4,5,6,11,12	386.21	132.84
2	Jul-Sep 2019	2, 7, 8	175	60.19
3	Oct-Dec 2019	9, 10	215.48	74.11
4	2018	13, 14	193.5	66.55

Table 8 - Emissions due to MMS and processing and analyses

ID	Project number	Pmms (Kg CO_2)	Ppa (Kg CO_2)	Total MM emission (Kg CO2)
1	10190098	0.027	0.250	0.277
2	10191445	0.033	0.300	0.333
3	10190154	0.045	0.417	0.462
4	10190188	0.007	0.068	0.076
5	10190276	0.042	0.384	0.425
6	10190300	0.009	0.083	0.092
7	10191114	0.025	0.234	0.259
8	10191146	0.014	0.133	0.148
9	10191678	0.008	0.075	0.083
10	10191897	0.055	0.505	0.560
11	10190095	0.210	1.935	2.145
12	10190218	0.025	0.234	0.259
13	10181565	0.154	1.418	1.572
14	10180791	0.036	0.334	0.370

Table 4 - Total emissions MM scenario 1

ID	Travel emission (Kg CO_2)	Electricity emission (Kg CO_2)	Total emission (Kg CO_2)
1	26.76	0.277	27.04
2	1.24	0.333	1.57
3	43.20	0.462	43.66
4	19.26	0.076	19.34
5	56.96	0.425	57.38
6	114.36	0.092	114.46
7	55.51	0.259	55.77
8	55.58	0.148	55.73
9	41.98	0.083	42.06
10	77.40	0.560	77.96
11	20.12	2.145	22.27
12	53.86	0.259	54.12
13	46.88	1.572	48.45
14	62.74	0.370	63.11

Table 9 - Total emissions MM Scenario 2

Group ID	Project ID	Travel emission (Kg CO_2)	Electricity emission (Kg CO_2)	Total emission (Kg CO_2)
1	1,3,4,5,6,11,12	132.84	3.737	136.57
2	2, 7, 8	60.19	0.740	60.93
3	9, 10	74.11	0.643	74.76
4	13, 14	66.55	1.941	68.50

VIII. Interview schedule: Involving the chain

Bachelor thesis questionnaire 2

Instructions for the interviewer

- Ask permission to record
- Ask if interviewee wants to stay anonymous
- Make the interviewee aware of the fact that the results will be published
- Respondent number:
- Ask all questions, do not skip any
- Keep the order as indicated
- Never to give own opinion

Respondent number	
Name interviewee	
Name interviewee	
Interview date	
Time	
Place	

Interview introduction

- Introduction of the subject
  - MM
  - CO_2PL
  - LBA Groep and University of Twente
- Contribution of the interviewee
- Explaining the types of questions
- Explain how the interview is processed: recording
- Duration of the interview: 10-15 minutes

Interview

First, I would like to talk about you and the company/water Authority.

1. Could you please introduce yourself and explain your function?

2. What measures does ……. already take in your expertise to reduce CO_2 emissions?

3. What could be improved, or could you think of implementations or pilots, in your area, Geodesy, that might also reduce CO_2 emissions in the future?

Now, I would like to ask you some question relating to my thesis, regarding MM and CO_2 reduction.

4. Do you have any experience or affinity with MM in general and what applications do you know?

5. In the 14 projects that were researched were related to surveying current situations or topography. CO_2 could be reduced with approximately 72% in general by replacing the TWM for MM, did you expect this and why?

6. Does this make using MM more attractive to implement?

7.
    a. **Anacon & Heijmans:**
    Literature research revealed that MM could also be applied at tunnel surveying, cable mapping, asset management and smart city applications. Do you think MM could have a contribution to reducing CO_2 here or on a wider scale as well?
    b. **Water Authorities**
    Literature revealed that MM can be applied for dike surveying or shifting of dunes. As water Authority, how do you see this, and do you think MM could have a contribution to reducing CO_2 here as well?

8. By knowing MM does reduce CO_2 emissions on replacing traditional road surveying work, could you think of applications where MM could serve more purposes and might also reduce CO_2 emissions?

Closure

- Do you have any other remarks regarding the subject of this interview that might be of value for my research?
- Thank the interviewee for his/her time and repeat what will happen with the data retrieved from the interview.
- Explain that a verification is needed to confirm that what goes into the report is true according to what the interviewee said.

IX. Interview summaries: Involving the market chain

Note:

- These interviews have been recorded and transcribed verbally.

- This transcript is written in Dutch as the interview was also carried out Dutch.

- The transcripts are not publicly published due to privacy reasons but are available on request.

Respondent number	1 / 3
Name interviewee	K. Margry (R)
Name interviewer	Rens Ampting (I)
Interview date	10/06/2020
Place	MS Teams

Margry (2020) is coordinator of the Geo-team at water Authority Rijn en IJssel, within the ICT unit. The water Authority is a governmental institution and hires contractors like LBA Groep to perform projects. Since the water Authority is a governmental institution, their ambitions to reduce CO_2 emissions is quite high Margry (2020) mentions. When projects are outsourced there is also looked at the CO_2 footprint. The geo-team contributes to reduction of CO_2 emissions by digitalising information of the outside. In that way, people are less likely to visit a certain location to measure something, which reduces the number of trips made. However, the CO_2 footprint is not decisive in choosing the contractor. That is primarily based on which contractor provides the best solution against the best price. This could be improved Margry says.

The gathering of information and data is commonly done through the TWM, but this is subject to change. Satellite data becomes more available and the water Authority is looking at other ways to gather information. The water Authority is also working on a pilot where a crane that mows the waterways directly measures the depths as well. The cranes or tractors are already driving there, so emissions are reduced by using the same work, upgrade it and serve multiple goals. This might also be possible with Mobile Mappers. The problem with MM from the road is that the data is limited to the road. Water Authorities are also interested in data that is not along the road such as creeks of smaller waterways.

Work is given under market conditions. The contractor with the best price and solutions gets the project. The techniques that are used by the contractor, such as MM is decided by them. MM is more attractive since more data is gathered, which could be used later or in other projects by the water Authority. The TWM usually provides one set of data, e.g. the hight of some points on the dike. Whereas, MM would be able to cover more areas of the dike which could be used for other purposes in the future, wherefore returning to the project area might not be necessary anymore. Margry describes that outside of just road mapping, there is a huge world to increase CO_2 reduction. Also when you are able to look through vegetation and are able to look underwater with use of echo loading. The final measure that is proposed is to make use of the environment, and traffic movement that is already there.

Respondent number	2 / 3
Name interviewee	R. Mengerink (R)
Name interviewer	Rens Ampting (I)
Interview date	15/06/2020
Place	MS Teams

Mengerink (2020) is co-founder of Anacon-Infra. A Civil Project bureau in Borculo. They primarily do project related work in preparation of civil engineering work for mainly municipalities, provinces, and water Authorities. Regarding the contribution to reduction of CO_2 emissions, Anacon-Infra try makes use of sustainable materials. This also depends on the client. Their company building is also made more sustainable by introducing new lightning, use of solar panels and investing in more environmentally friendly air conditioning. The company does not have surveyors employed, but have some cars running. When they are replaced, the alternative of more sustainable or electric cars are considered.

Mengerink perceives MM as making scans from which products are generated or being delivered to Anacon-Infra, as a foundation for project preparations and for the purpose of making animations and visualisations. The relation between MM and CO_2 reduction has not been made before, with he found quite interesting. The link is not made, since Anacon only uses the method in project preparations, for which they get delivered MM surveys.

Anacon-Infra works a lot with municipalities, and to Mengerink's knowledge, municipalities do not care so much about how measurements are retrieved. Either with MM or with the TWM. They are not thinking about 3D applications yet, wherefore they would need scans; however pilots are set up for smart city applications. The work we do, where projects are prepared like drawings and project specifications, are still primarily based on the traditional 2D way, however the transition has been made to digitalisation. For the time being, Mengerink does not see a major change yet, because clients do not yet recognise the advantages of MM.

Anacon-Infra were looking for the singular gathering of data, which is done through MM, with which you have a lot more information and a more rapid acquisition, compared to the TWM. It is used for accurate measurements as well as for the purpose of 3D visualisations, to show the new design in the surroundings it will be implemented. However, this is little provided to external relations since municipalities often take enough with just the drawing. The advantages are not seen, and they would think it would be too expensive.

Mengerink thinks interest in working with 3D will increase, of which MM is a part as well. Mengerink is working on applying 3D across all the project preparation procedures. To him it does not make sense, surveys are conducted in 3D, while everything is then converted to 2D in drawings and specifications, whereafter it is converted to 3D again for work in the field. Mengerink sees a lot of potential in applying 3D across the whole process, also in management and maintenance. If 3D is applied in the whole process, quality would rise, and costs would decrease. However, this is primality proved on prestigious projects and not so much in smaller urban or inner-city reconstruction. Apparently, their clients, e.g. municipalities are not ready yet.

On the question whether 3D and MM is not recognised yet, Mengerink says that it is recognised, but that clients care little for how their data or projects are achieved. Whether it is with MM or with the TWM. Currently, the tender that is cheapest and offers the best solution to the projects, gets it. Where little is looked at reduction or the way the results are conceived. However, if MM is used in the whole process, which is not done now, the additional value becomes way higher. Mengerink closes with the conclusion that the threshold for using MM is quite high, but if clients have seen the end product, there will be more possibilities to apply it.

Respondent number	3 / 3
Name interviewee	P. van Dueren den Hollander (R)
Name interviewer	Rens Ampting (I)
Interview date	16/06/2020
Place	MS Teams

P. van Dueren den Hollander (2020) is one of three managers in the management team of Geodesy at Heijmans and is mainly focussed on multidisciplinary projects, in which civil and road construction projects come together, like monitoring.

Heijmans conceives sustainability concerning the 3P's. People, Planet & Profit. The focus is specially lied on digitalisation, with which reduction CO_2 emissions is realised, by applying innovative techniques, like remote machine control, with use of 3D models. Heijmans also has their own online platform in order to digitalise further. In addition, using innovative techniques, reduces the deploying of people, and thus reduced emissions.

P. van Dueren den Hollander is quite familiar with applications of MM, like the collection of data at an early stage for design purposes, and for surveying current situations. MM is also more used as an intermediate mean, as the lead time between scan and 3D design becomes smaller, e.g. for quality check and optimisation purposes. It is therefore quality increasing and more risk averse. Less assumptions are made then with the TWM since data of the actual situation is available. At the moment, when the lead time between scanning and making a 3D model reduces, the possibility areas will increase. Chances for future use is definitely there.

By implementing MM, more data is gathered. The amount of data on projects is huge. Therefore, risks management is more in control. However, the processing and storage of all this data is still an issue. Sharing huge amounts of data would slow down software and sometimes this means the same data is used on two different locations, which is a risk. Therefore, data is aimed to be store offline and locally to increase the processing speed and reduce risks. Although, solutions for this issue are there, by using online platforms or making use of vector tiling. In this way, only a small proportion is being worked on in phases. This reduces the load on the work that is carried out and increase processing speed.

MM gives more knowledge on where the risks are. Therefore, risk management is easier for maintenance of assets for example. Guardrails have certain criteria concerning dimensions. By surveying with MM, instead of manually measuring with the TWM, analyses are done on the guardrails and specific locations could be identified that need maintenance. Doing this, avoids using road blocks and increases traffic flow and safety.