BI Norwegian Business School - campus Oslo

GRA 19703

Master Thesis

Thesis Master of Science

Performance measurement in Lean Construction

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Start: 15.01.2019 09.00

Finish: 01.07.2019 12.00

Acknowledgements

We wish to show acknowledgment and appreciation to the contributors who have guided and helped us through this master thesis. We have truly enjoyed exploring this topic and gaining more insight into such an important and interesting industry.

Our first and foremost acknowledgment goes to our supervisor, Lena Bygballe; who has guided us throughout this process and provided us with valuable feedback. Secondly, we are truly grateful for the hospitality given by Veidekke and especially our contact persons, Fredrik Svalestuen and Morten Barreth, for warmly welcoming us to Veidekke and their construction projects. This opportunity provided us with valuable insight and knowledge of the industry and our research area. We also wish to express our gratitude to all of those who willingly participated in the interviews, their insights and contributions have been of great importance for our research.

Lastly, we want to express our deepest appreciation to our family and friends; all of your support, patience, and encouragement have enabled us to complete our studies successfully. Ceyda wants to thank her better half for all the love and support throughout this process; I really appreciate your kindness. Sanne Kristin wants to thank her better half, Rune; your endless love, patience, and guidance have truly helped me throughout this journey, I am forever grateful.

To our mothers, Kamuran and Solveig; we are truly thankful, without you, we would not be who we are, and where we are today - thank you for always encouraging and believing in us!

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Abstract

The construction industry accounted for approximately 16% of Norway's GDP in 2018, and a well-functioning and efficient industry is thus of great importance (Øye, 2019). However, it is commonly recognized that the productivity and efficiency in the construction industry have been stagnated for a long time. As a result, more attention has been drawn towards figuring how to counteract this negative trend. During the past two decades, Norwegian construction companies have implemented various practices and methodologies aimed at their performance, where one of these practices is the Lean methodology. During this period, the Lean Construction has grown in prominence and is considered one of the most appropriate initiatives to improve performance. In addition, some researchers have claimed that by conducting performance measurements, it is possible to identify areas for improvements. Thus, this thesis will try to gain a better understanding of how performance measurement is used in Lean Construction by investigating the formal structures implemented and used for measuring performance and how this is affected by informal conditions. Hence, our research aims to answer the following two research question:

- *How is performance measured in Lean Construction?*
- *Why, or why not, should performance be measured in Lean Construction?*

Our research is based on an exploratory case study of Veidekke ASA, where Lean Construction has been used since early 2000. This has provided us with an in-depth understanding of the phenomenon by conducting 18 semi-structured interviews, six observations, and participation at LC-NO seminars.

The findings from our research revealed that tools and systems must be used adequately and in a coherent matter to conduct performance measurements with the aim for continuous improvement. Moreover, informal conditions must be taken into consideration and focused upon in order to optimize the potential outcome. However, our thesis concludes that there is not a yes/no answer to the question of if performance measurements are in accordance with Lean thinking. This is because our findings demonstrate that this highly depends on several aspects and conditions that need to be addressed, such as what the goal of the measurements is.

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List of Abbreviations

ALP - Average labor productivity
CDM – Collaborative Planning in Design Management
CP – Collaborative Planning
CPM - Collaborative Planning in Production Management
GDPR - General data protection regulation
IGLC – International Group for Lean Construction
LC-**NO** - Lean Construction Norway
LPS - Last Planner System
NSD - Norwegian center for research data
NTNU - Norwegian University of Science and Technology
PPC – Percent planned completed
SSB – Statistics Norway (Statistisk sentralbyrå)
TA – Task Anticipated
TMR – Task made ready
TPS – Toyota Production System
VSM - Value stream mapping
WWP - Weekly Work Plan

1. INTRODUCTION

In this master thesis, we hope to add some insight into the subject of performance measurement within Lean Construction. To meet this ambition, we perform a case study, discuss various aspects of how and why performance is measured in the construction industry, and how this should be done within the Lean methodology. This opening chapter of our thesis provides an overview of the background and our motivation for the thesis topic, followed by a discussion on the justification and expected contribution of our research. Then, we present our research questions and provide a short introduction of the empirical setting used to address these questions. Finally, we give an overview of the structure of our thesis.

1.1 Background and motivation for the thesis

Our motivation for this thesis topic started with a presentation of Lean Construction in one of our courses at BI. We were curious to learn more and we, therefore, joined the Lean Construction in Norway (LC-NO) network to gain more knowledge and insight into the subject. Through our logistics-course professor, we were introduced to Fredrik Svalestuen, who is a production and process manager at Veidekke ASA (Veidekke), one of the largest construction and property development companies in Scandinavia (Veidekke, 2019a). He is the chairman of LC-NO and responsible for maintaining and developing Veidekke’s adaptation of Lean Construction, which Veidekke refers to as Collaborative Planning (CP). After several meetings and discussions with Svalestuen, there seemed to be an endless list of exciting research topics within the field of Lean Construction and how to increase productivity in the construction industry. However, an area that seemed particularly important was performance measurement in Lean Construction, and we decided that this would be our research subject.

The construction industry accounted for approximately 16% of Norway's GDP in 2018, and a well-functioning and efficient industry is, therefore of great importance (Øye, 2019). During the past two decades, the Norwegian construction industry accounted for the second largest value-creation in the country (Todsen, 2018). However, it is a widespread belief that the productivity and efficiency in the construction industry have been stagnating for a long time. According to a report written by the Productivity Commission (NOU 2016), the industry needs to focus more on the efficient utilization of labor resources in order to increase long-term productivity growth. Further development of Norway's prosperity requires that productivity is improved (Produktivitetskommisjonen, 2016). This is not only an issue in Norway, the same trends can be observed globally (Barbosa, Mischke & Parsons, 2017a), and it has been documented that the growth in productivity is significantly lower in the construction industry when compared to other industries and sectors in several countries (Allmon, Haas, Borcherding & Goodrum, 2000; Barbosa et al., 2017b; Force & Britain, 1998; Miller, Strombom, Immarino & Black. 2009). This opinion was also supported by Forbes and Ahmed (2011) who argued that while most industries over time typically achieve productivity improvements, the construction industry has proven to become less efficient and thus in an increasing need of better decision making and planning processes. As illustrated in the graph below (Figure 1), the productivity in the construction industry has declined by roughly 10 % during the period 2000 - 2016, while productivity in the Norwegian economy on average has increased by some 30 % during the same period (Todsen, 2018).

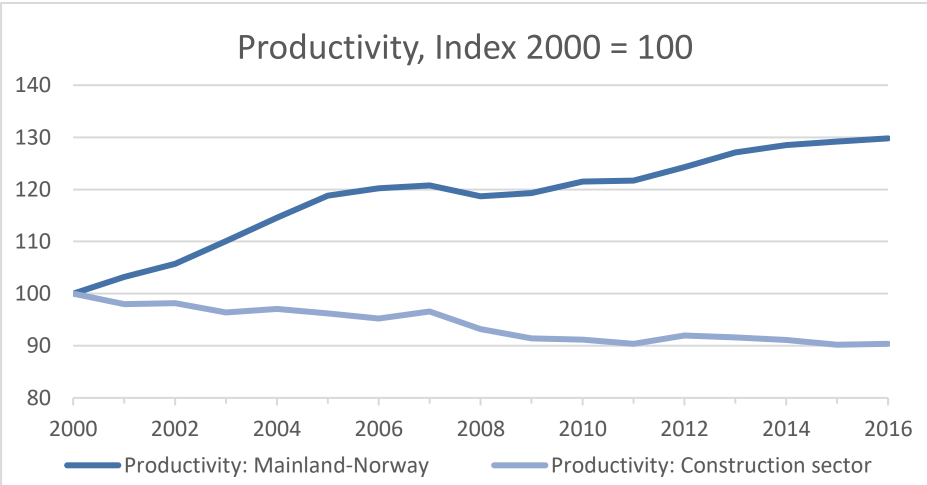


Figure 1: Productivity Index from Todsen (2018)

As a result, more attention has been drawn towards figuring how to counteract this negative (Aziz & Hafez, 2013; Bertelsen, 2004; Koskela, 2000). During the past decade, Norwegian construction companies have implemented various practices and methodologies aimed at their performance (Langlo & Andersen, 2016), but results have been mixed, and it seems like companies still find it challenging to evaluate the effects of implementing these practices. One of these practices is the Lean methodology, were Lean tools, techniques, and concepts have been highly promoted within the construction industry over the past couple of decades (Ballard

& Howell, 2004; Ballard, Tommelein, Koskela & Howell, 2002; Barbosa et al., 2017a; Daniel, Pasquire, Dickens & Ballard, 2017; Kalsaas, 2017; Knotten & Svalestuen, 2014; Porwal, Fernandez-Solis, Lavy & Rybkowski, 2010). Moreover, during this period, the Lean Construction methodology has grown in prominence and is considered one of the most acknowledged initiatives to improve performance (Egan, 1998; Sage, Dainty & Brookes, 2012). In their research, Barbosa et al. (2017a) argue that implementing Lean principles, with its focus on reducing waste and variability in the project planning and coordination, could solve the problem of productivity stagnation. In addition, some researchers have claimed that by performing performance measurements, it is possible to identify areas for improvements (Fosse & Ballard, 2016; Hamzeh, Ballard & Tommelein, 2009). However, Nadim and Goulding (2011) argue that the construction industry shows little intention and will to adapt and apply to new working methods and tools.

However, it is not all doom and gloom, as some research has also confirmed that the construction industry has for some time shown signs of improvement (Ingvaldsen & Edvardsen, 2007; Kalsaas, 2013; Thune-Holm & Johansen, 2006). The low productivity rates are debated, and our empirical findings indicate that the negative view might be biased. For example, an increase in the use of prefabricated components means that an increasing share of the construction industry's output has been moved away from the building site (Langlo & Andersen, 2016), and with the resulting productivity gains not necessarily be credited to the construction industry. The following quote from one of our interviews illustrates this point:

"No one focuses on the industrialization of the construction process since it does not appear in any figures. This is because production has moved from the construction industry to another type of industry category. In other words, one is not able to capture this change and thereby understand how the improvements affect productivity. Thus, one measures the productivity on a much smaller part of the production. Many of our materials are prefabricated, such as precast concrete, plaster, steel studs, and the kitchen is delivered fully assembled and just needs to be mounted onto the wall. We probably build an apartment twice as fast today than we did 20 years ago, but it does not appear anywhere." Interviewee # 12

This illustrates the importance of correct performance when discussing productivity in the construction industry. As already mentioned, there are several ways to try to improve performance, with Lean becoming a common initiative for this purpose. Still, performance measurement is in general quite challenging to implement successfully, and several researchers have pointed out that the process of implementing formal structures, such as systems, tools, and techniques for measuring performance can actually itself make it more challenging to measure performance (Porwal et al., 2010; Powell, 2004). Furthermore, other researchers argue that the challenge is related to how performance is measured and how it is perceived (Bygballe, Endersen & Fålun, 2018; Bresnen, 2009; Green & May, 2005; Sage et al., 2012), which we in this thesis will define as informal conditions. Thus, we will try to gain a better understanding of how performance measurement is used in Lean Construction by investigating the formal structures implemented and used for measuring performance and how this is affected by informal conditions.

1.2 Research contribution and justification

Considerable attention has been directed towards the (perceived) negative trend in productivity in the construction industry, and there seems to be a need for a clarification of the process and purpose of performance measurement within Lean Construction. This thesis aims to contribute to the research field of Lean Construction by examining the different aspects of performance measurement within the context of Lean Construction. The thesis has both practical and theoretical relevance, meaning that our research is both relevant and significant because it touches upon many of the challenges discussed related to productivity in the construction industry. The thesis is innovative in the sense that scientific literature is rather scarce when it comes to topics like the usefulness and role of performance measurements in Lean construction. This thesis, therefore, aims to contribute and provide additional insight and fill the identified research gap.

The practical relevance of our thesis is related to the fact that performance measurement is considered to play a significant role when discussing productivity, and the construction industry can benefit from emphasizing which aspects are important in order to increase productivity (Ballard & Howell, 1994a; Kaplan & Norton, 1992; Lantelme & Formoso, 2000; Liu, Ballard & Ibbs, 2013; Neely et al., 1996; Neely, 1999). Overall, our research aims to provide a holistic view of the various views and perceptions of the industry players regarding performance measurement and Lean Construction. The empirical findings in this thesis are a result of the opinions and perspectives of the many key employees in the various construction projects at Veidekke we have studied, which have been supplemented with contributions from industry and academic experts. With regards to the feasibility of our study, we have been working closely with Veidekke throughout the process of writing this thesis. Moreover, our primary contacts in Veidekke have been very engaged and helpful in this research and therefore provided us with indispensable information and insight that we believe has contributed to both high quality and relevance of our research. Hopefully, our findings will provide a better basis for discussing the relevance and usefulness of performance measurement in Lean Construction, and also provide some reflections for best practices when measuring performance in Lean Construction.

1.3 Research Questions

The overall objective of this thesis is to add insight into how and why performance is measured in Lean Construction by investigating and discussing various aspects of the subject, in theory, and practice. One of the main aspects we focus on is the formal structures, which is characterized as the mechanisms and tools that create a basis for accountability and predictability for the raw data collected on performance. However, as mentioned already, measuring performance can be challenging, and the formal structures are not always sufficient. One must therefore also consider how performance measurements are implemented and used, and how the informal conditions (i.e., the more “soft” values) create a basis for culture and commitment for the methodologies (Bygballe et al., 2018; Hall, 1977; Harrison & McKinnon, 2007; Marchan, Welch, & Welch, 1996; Sage et al., 2012). As such, we find it interesting to not only investigate how performance is measured but also why one should measure performance and how it is perceived. The interplay between these two aspects is crucial in order to achieve improvements, and we have, therefore included these in our research questions to answer our overall objective.

Precise research questions are necessary to be able to identify which literature and what data is important for our study, in addition to providing a guideline for the research process and to limit the scope of our research (Bryman & Bell, 2015). In order to make a thorough investigation of the subject, we define two (equally important) research questions to frame the study:

RQ1. How is performance measured in Lean Construction?

Our first research question aims to provide an understanding of how performance is measured within Lean Construction. To narrow the scope, we do this by investigating which metrics are used within the Last Planner System (LPS) to measure performance. The LPS is one of the most used methodologies in Lean Construction (Kalsaas, 2017), and is perhaps the most useful when searching for answers and theory according to our overall objective. By focusing on the LPS, our research should be highly relevant to construction companies. Another important aspect is deciding who should be responsible for the performance measurements, and how one should implement the measurements given the challenges that could occur. Although formal structures and tools, such as LPS, are important mechanizes to define and use, it also important to take into consideration the more informal aspects such as motivation, and barriers behind performance measurements within Lean Construction. Our first research question focuses more on the specific concepts and tools, whereas the second research question is aimed at addressing a more overall understanding of performance measurements in Lean Construction.

RQ2. Why, or why not, should performance be measured in Lean Construction?

Previous research shows that there is a split view on whether performance measurements are necessary or a value-adding activity (Ballard & Howell, 2004; Bjørnfot & Stehn, 2007; Liu, Ballard & Ibbs, 2013; Womack, Jones & Roos, 1996, 2007). Our thesis will, therefore, also aim to address the question of whether performance measurement is in accordance with Lean thinking.

1.4 Empirical setting

This thesis is written in collaboration with Veidekke, which is one of the largest constructions and property development companies in Scandinavia (Veidekke, 2019a). Veidekke has used the Lean methodology for several years and has developed its own methods and systems designed to increase their productivity. For instance, in 2003, Veidekke developed a method called Collaborative Planning (CP) (Bølviken, 2014, p.10). This can be viewed as a customized version of the LPS, which is a system for planning and management within the context of Lean. The introduction of the CP was the second of a total of three phases in the process of developing "Vi i Veidekke" (We at Veidekke). Together, the three phases aim at improving the culture, the economic value creation, and the physical production process. Veidekke's overall vision is to obtain a "value-creating interaction" between the customers, employees, management, and suppliers (Veidekke, 2015). CP focuses on involving the subcontractors to a greater extent at the beginning of the planning process, in order to take advantage of their previous experience and knowledge. The goal is to achieve a more engaged collaboration between the various construction disciplines and managers in order to achieve better quality, performance, and execution of the work as well as a better financial result. By conducting a case study of Veidekke, which has used this system in several of their projects over the past 17 years, our thesis gains useful insight into the practice of measuring performance, which naturally also serves as an important contribution to answer our research questions.

However, due to capacity constraints, Veidekke has yet to study the organizational effects of using CP in their projects. They especially emphasize the challenges that occur when measuring performance according to the LPS. In this thesis, we have conducted a single case study where we base our research on six different construction projects where Veidekke is the main contractor. By including several projects, we hope to gain a holistic overview and a better understanding of the various perceptions of performance measurements in the construction projects.

1.5 Structure of the thesis

In the coming parts of this thesis, we will first describe the research methodology used. This is followed by the theoretical background in chapter three, where theories and previous studies associated with the research area are presented. Next, in chapter four, the analysis of empirical findings from our case studies will be outlined. In chapter five, we will discuss our main findings and compare them with the theoretical background. Finally, in chapter six, we present our conclusions, recommendations, and suggestions for further research. The following figure (Figure 2) illustrates how our research is structured and the interplay between the different chapters.

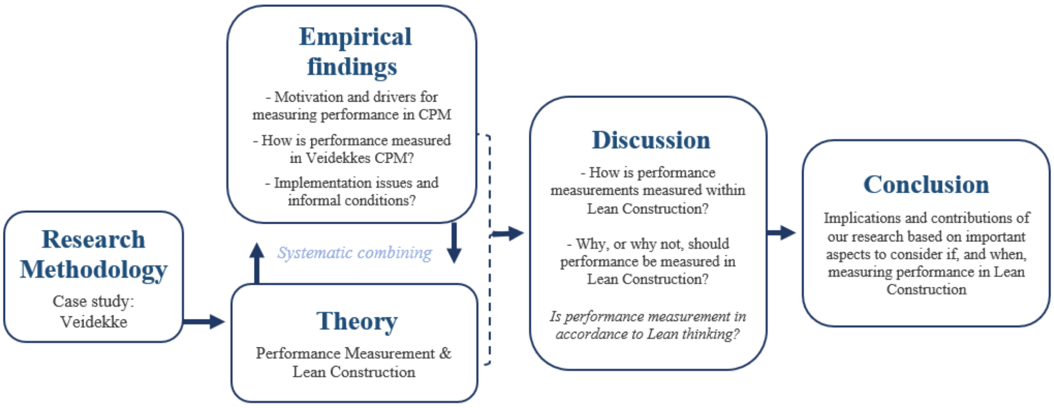


Figure 2: Thesis structure

2. RESEARCH METHODOLOGY

In this chapter, we present a thorough description and justification of the research methods and scientific approach used in our research. Firstly, we present our research strategy and design, where we discuss our scientific approach, followed by the appropriateness of the mixed method research strategy for our case study. Secondly, we present the different methods of data collection and the analytical process within the data analysis strategy. Finally, we will discuss the scientific quality of the study, followed by the research limitations.

2.1 Research Strategy

The research strategy is defined by Bryman and Bell (2015, p.37) as "*a general orientation to the conduct of business research*" and should provide a description of the approach of the research. The overall objective of our research has been to unveil why and how performance is measured in Lean Construction and add insight into whether performance measurement is in accordance with Lean Thinking. We have conducted an exploratory case study of Veidekke in order to answer the overall objective and the presented research question, where we have interviewed participants from six of their constructions projects to get an in-depth understanding of our research area.

2.1.1 Scientific Approach

Traditionally, researchers distinguish between two theoretical approaches to scientific research; the division is most commonly known today as the deductive vs. inductive method. The deductive approach aims at generating propositions and hypothesis based on what is known about a domain and its theoretical foundations, and then design a strategy aimed testing them in the real world (Bryman & Bell, 2015; Wilson, 2010). The inductive approach is in the opposite direction from the deductive and is concerned with systematically generating new theory emerged on data from the empirical research (Bryman & Bell, 2015; Wilson, 2010).

The iterative approach is a method that incorporates both approaches, i.e., research and theory (Bryman & Bell, 2015), whereas systematic combining, presented by Dubois and Gadde (2002), is a particular type of the iterative approach. The systematic combining appears to be closer to the inductive viewpoint than the deductive and is a way of conducting case studies and is referred to as an abductive approach. It is a process method that involves moving back and forth between the theoretical framework, empirical fieldwork and from one research activity to another, and in that way evolves simultaneously with the case analysis (Dubois & Gadde, 2002). The authors further argue that this approach enables the researchers to expand their understanding of both theory and empirical phenomena and is particularly useful for developing new theories. Therefore, systematic combining was considered suitable for this thesis, as it, in line with the systematic approach, follows a continuous interplay between empirical data and established theory throughout the process. This approach also allowed for refinement of existing theory based on our findings, and in that way allowed us to contribute to the theoretical understanding of measuring performance in Lean Construction.

2.1.1.1 Literature study

The theoretical basis for this thesis draws upon synthesizing literature on suitable articles and previous studies that can contribute to relevant theories and concepts to our research. The purpose of the literature study is to provide a solid theoretical foundation to help develop the framework of the thesis and the interview guide. Moreover, existing literature can give an indication of which research methods that have been previously conducted (Bryman & Bell, 2015). We began our research by investigating existing theory on performance measurements in Lean Construction, before conducting interviews and collecting other primary data collection. Our literature study is based on articles, conference papers, reports, and books written with relevance to the research question.

Moreover, the literature on the established topics was gathered from different journals such as International Journal of Production Economics, International Journal of Operations & Production Management, Lean Construction Journal, Journal of Construction Engineering & Management, Management Decision and American Psychologist. Literature regarding the approach of performance measurement was assembled from a range of different sources. In our literature study, we notice that there seems to be a lack of recent research on distinct topics. However, we have read several conference papers published by Lean Construction

Institute and IGLC to gain insight into the ongoing discussion in this field. The data collection found place during our document analysis in order to create a basis for our interview questions and to gain a holistic view of the processes for each project.

Conference proceedings were a part of our study since this research was based on the understanding and practice of performance metrics in Lean Construction throughout the execution process. Such studies of conference proceedings aim to cover the phenomenon of how and why the research object emerge, evolve, or terminate over time (Langley, Smallman, Tsoukas, & Van de Ven, 2013). According to the same study, process conceptualizations is considered to be a causality as formed through chains of actions rather than through abstract correlations.

2.1.2 Research Method

Within research strategies, we distinguish between quantitative and qualitative research methods. Quantitative and qualitative are two research methods that specify how the researchers choose to collect and analyze the data from the research case (Bryman & Bell, 2015). Quantitative research methods are based quantification of the findings and focus on what is measurable or quantifiable, such as statistics. On the other hand, the qualitative research method is based on textual or oral information, such as interviews and observations, and expresses the findings by words (Bryman & Bell, 2015; Ghauri & Grønhaug, 2010; Saunders, Lewis, & Thornhill, 2016). Khan (2014) states that qualitative research methods enable the researchers to explore some phenomena and factors that previously have not been discovered. Hence, our observations could contribute to a better understanding of the dynamic surroundings in the six different projects at Veidekke (Bartunek, 2012). Research has shown that the high dependency of only using one method can decrease by combining several qualitative and quantitative approaches within a case study (Scholz & Tietje, 2002).

This study aims to integrate both quantitative and qualitative analysis, as we believe that the readers in this way will gain a more complete and comprehensive understanding of the research. The mixed method research has over the years been used to examine and conduct business studies, and is often recommended to get an understanding of the complex reality since the single approach will not be able to capture reality in all its aspects (Bryman, 2009; Dubois & Gadde, 2014). However, Dubois and Gadde (2014) argue that it is important to clarify the specific features of the different research approaches before combining research methods. This is because the research methods greatly rely on different assumptions that not necessarily are compatible.

By applying the mixed method, we are able to decide on both how to weigh and sequence the two main research methods when conducting our study. Given the nature of this study, a qualitative data collection approach is emphasized, since the qualitative method provides in-depth knowledge of the research area, allowing us to investigate the how, what and why questions thoroughly. However, the quantitative data collection and analysis will have a subsidiary role and is conducted concurrently with the qualitative data. The data used for our quantitative analysis is collected by project managers at Veidekke and further cleaned and analyzed by us. This process will be further explained in section 2.4 Analytical Process. We believe this strategy helped us to gain a better understanding as it enabled us to investigate the research questions from different angles and in that way, clarify if there are any potential contradictions or unexpected findings. Additionally, accessing raw and semi-processed data on PPC enables us to scrutinize and critically evaluate the metrics and get an in-depth understanding of root-causes for the measurements. The combining of the two methods also makes us able to corroborate and validate the findings from the qualitative research approach.

2.2 Research Design: A case study

The research design is described as a framework for the process of collecting and analyzing data (Bryman & Bell, 2015). The properties and advantages of the mixed research method have been discussed to be the most appropriate, considering the practical feasibility of the research design. An example of this is a case study, which is a popular and often applied design in business research (Baxter & Jack, 2008; Stake, 1995). It focuses on a bounded event with a purpose to analyze how the context and the complexity of the subject affect the outcome (Bryman & Bell, 2015; Yin, 2014). According to research, case studies are an excellent foundation for several contextual aspects, for instance, for theory refinement and development, deeper understanding of data and the dynamics around the phenomenon of interest (Dubois & Salmi, 2006; Ellram, 1996) Additionally, as mentioned, this research design favors qualitative methods and is, therefore, beneficial to get an in-depth examination of a real-life situation (Eisenhardt & Graebner, 2007; Siggelkow, 2007). Given the exploratory nature of this thesis, our research favors a case study approach as it allows us to elucidate the different aspects of the phenomenon of performance measurement in Lean Construction.

To answer our research question, we studied the phenomenon in Veidekke and some of their construction projects. Veidekke, which is the case study of interest, has used the Lean methodology for several years and has since 2006 used Collaborative Planning (CP) as an approach to increase their productivity. Therefore, Veidekke seems to be a highly relevant empirical setting for this thesis. A part of CP is to conduct performance measurements, and it was emphasized by Svalestuen that they were missing a proper clarification of how, what and why performance is measured in Lean Construction.

We were introduced to six residential construction projects, which all represented different characteristics regarding project goals and complexity, and were in different phases of the project life cycle. These projects are not considered as sub-cases in this thesis, but more as the empirical setting, since we get more insight by interviewing participants from these six different projects than by only looking into one project. This variety also provided us with valuable insight into how performance measurement is perceived and implemented across the different projects, in addition to a better understanding of the motivation and barriers towards measuring performance. Although we compare some of the systems and approaches used to measure performance across some of the projects, these projects will provide a complementary, rather than a comparative, starting point for our research. The six residential projects are Frysjaparken, Nyegaardskvartalet, Ulvenparken, Hagebyen, Sølvparken, and Gartnerkvartalet, with Veidekke as the main contractor.

Figure 3: Construction projects at Veidekke

Sølvparken aimed to follow CP completely throughout the project execution, and should therefore implicitly implement, among other things, the metrics presented in their guideline. In contrast, the five other projects have not been restricted to emphasize CPM in the same matter by Veidekke. In other words, the six projects all have different experiences with Lean Construction, and thus, various approaches to the methodology. Additionally, as seen in Figure 3, the projects were in different phases in the project life cycle. Thus, this enabled us to thoroughly investigate the phenomena by capturing and comparing important aspects from projects in the planning phases to projects which were closer to completion or completed. We believe that the projects thereby complement each other and provided us with a broader basis to reach our research questions.

2.3 Data Collection

According to Dubois and Gadde (2002), an abductive approach will be suitable when the research is conducted through matching, reviewing, and directing theory with the empirical analysis. As mentioned, the abductive approach was considered useful since the case study is dependent upon the methods and techniques that are used for the data collection (Bryman & Bell, 2015). The collected data can be differentiated to be either primary or secondary data as they respectively derive from either internal or external source of data (Jacobsen, 2005). We chose to include some case-specific data, such as evaluation templates, performance measurements, and document analysis, in order to reveal additional findings. This was done in order to reduce the complexity of our research as we looked at which type of information that was both accessible and necessary.

To ensure reliability and validity of the study, Yin (2014) argues that researchers should follow four principles of data collection: maintain a chain of evidence, use several sources of evidence, organize the evidence by using a database and carefulness when collecting evidence from electronic sources, which will be further discussed in section 2.5.

2.3.1 Primary data

Primary data for qualitative research is often collected firsthand by the researchers and serves the purpose of the research specifically. Which in our research was based on interviews, observations, participation, and attendance (Appannaiah, Reddy & Ramanath, 2010; Jacobsen, 2005). Evidence for case studies comes in both qualitative and quantitative formats, these being either: documents, archival records, interviews, participant observations, direct observations, and physical artifacts (Yin, 2014).

2.3.1.1 Interviews

Interviews are considered useful and important evidence in the case study (Ellram, 1996; Yin, 2014). Interviews with key participants from both projects can contribute with several reference points to, as mentioned, avoid subjective and misleading information. Additionally, interviewees can give the researchers insights into specific topics and an in-depth understanding of the factors and obstacles concerning the subject (Yin, 2014). However, we were aware that some opinions might be biased or lacking information. This was especially the case when we had to have *one* interview, with *two* interviewees. In case of any obstacles, interviews are favorable for researchers as it offers great flexibility in studies that are usually unpredictable. This flexibility allowed us to adjust the focus of our research during the "course of interviews" (Bryman & Bell, 2015).

A structured interview is the most restricted format of data collection as the researchers solely focus on predefined topics and issues. On the other hand, in an unstructured interview, the interviewee discusses a given topic, where the researchers do not interfere with asking or controlling the conversation (Bryman & Bell, 2015). In this research, semi-structured interviews were preferred since it allowed us to be both flexible but also allowed us to control and ensure that the discussion was consistent with the relevant topic (Yin, 2014). Through semi-structured interviews, we were able to elaborate on comparable questions and/or answers while being able to adapt the research accordingly to the new findings (Bryman & Bell, 2015). Also, it allowed us to ask follow-up questions that were not included in the interview guide (see appendix 2) (Kvale, 2007). The interview guide was based on insights from our literature study and was created to both ensure the flow in the interviews and to cover all the topics of interest. Additionally, this enabled us to gain an understanding of terms and concepts that we were previously unaware of. However, in accordance with the abductive approach, the interview guide was adjusted along the process.

We conducted a total of 17 interviews, with 18 interviewees, with a duration of approximately 45 minutes each. All the interviewees from Veidekke were pre-selected based on roles and projects with the help of Svalestuen and one Project Portfolio Manager. We chose to interview people within the different departments in the organization in order to include more diverse viewpoints among the participants. We found this variety of interview participants crucial to comprehend the different opinions and experience from interviewees at the headquarter to the fieldworkers. These interviews, along with observations and participation, played an important role in validating and understanding the data that were provided by Veidekke. This was also necessary in order to reveal any misleading information from our interviews. We also visited and conducted interviews with two representatives from another large construction company in Norway that also has focused on Lean Construction and performance measurement. Additionally, we interviewed and discussed the phenomena with field experts from BI Norwegian Business School and Norwegian University of Science and Technology to gain a broader insight into the field of research.

We want to emphasize that the interviews were held in Norwegian, and because of the new requirements and regulations regarding the GDPR, the interviewees are anonymized, and for the quotations, numbers are used as indicators for identifying which role each participant holds. We have performed a careful and cautious translation of the quotations from the interviewees. In addition to this, we tried to include relevant findings from each interviewee, in order to not solely focus on the minority of interviewees from these projects. Due to the NSD regulations, we are not able to compare the chosen projects with each other, meaning that this will unfortunately not be a part of our analysis. However, this contributed to reducing the risk of biased answers as the interviewees were ensured that they could voice their opinions freely. The following table provides an overview of the different groups of actors and the respective interviewees identified by numbers.

Company / Project	Interview with	Data collection / type		
Veidekke headquarter	A production and process manager and a project portfolio manager	Two interviews		
Other construction company	A development manager and a project manager	Two interviews		
Academia	A professor in *Project management and Performance measurement management* from NTNU, and a professor of Organizational Behavior from BI Norwegian Business School	Two interviews		
Construction projects at Veidekke		***Interviews***	***Observations***	***Quantitative data***
Frysjaparken	The project manager, the construction manager and one foreman	*Three interviews*	*Four observations*	*PPC measurements (raw data)*
Sølvparken	The project manager, the construction manager, the operational manager and one foreman	*Four interviews*	*Two observations*	—
Nyegaardskvartalet	The project manager and the construction manager	*One interview with two interviewees*	—	—
Ulvenparken	The research and development manager	*One interview*	—	—
Gartnerkvartalet	The project manager	*One interview*	—	—
Hagebyen	The project manager	*One interview*	—	*PPC measurements (raw data)*
Role of the interviewee		**Interviewee number**		
Project Portfolio Manager and Production Process Manager		1,2		
Project manager		3, 4, 5, 6, 7		
Construction manager		8, 9, 10, 11		
Academia and other key informants		12, 13, 14, 15, 16, 17, 18		

Table 1: Overview of data collection

2.3.1.2 Observations

Observations are when the researcher immerses into a group for an extended time, to observe behaviors and actions and listen to conversations among others and with fieldworkers (Bryman & Bell, 2017). The natural setting of a case study creates the opportunity for direct observations, Yin (2014) proposes that direct observations are one of the most common types of field visit method in case study research. Some of the environmental conditions or relevant behaviors will be possible to observe, assuming that the phenomena of interest have not purely been historical. This is supported by May (2002) who postulates that when doing thoroughly qualitative research, one should conduct both interviews and observations. Direct observations might work as an elaborate method in addition to other methods to get a different perspective on the matter, or it might provide affirmative or dissenting information about the findings. Participatory observation, on the other hand, is a special mode of observation in which the researchers are not merely passive observers.

Due to the nature of this case study, observations were necessary to get a proper understanding of the situation, and the behavior amongst the actors during the meetings and discussions. Field observations were conducted at Frysjaparken and Sølvparken, this provided us with valuable insight into meetings structures and their approach to measuring performance. The construction of Frysjaparken started in 2018 and has thus a well-implemented and applied meeting structure and method of measuring performance. Sølvparken, on the other hand, was at the very beginning of the construction phase and more focused on the planning phase. However, both projects found place in a real-life setting, which allowed us to conduct a great variety of observations of their performance measurement approach and their attitudes towards the process.

The observations were useful to get a proper understanding and insight into how they in practice, do or do not measure performance. We found the observations necessary when trying to get an understanding of the different approaches toward performance measurement, how the actors were involved in the process, and how they acted and participated during the various meetings. It also allowed us to verify whether the information we received through the interviews were correct. Being present in their work environment provided the opportunity to observe the surroundings of the interviewees and perceive them as they interacted with their colleagues. Additionally, we gained insight into their meeting and planning structure, and also how the different parties were or were not a part in the evaluation process.

The observations provided information regarding the empirical context and some ideas for whom to interview and which questions suited more relevant to ask. However, in order to stay professional during this process, the researchers tried to maintain some distance from the interviewees. Both researchers took field-notes during the observations, which were subsequently discussed and compared in order to get the notes as objective as possible. Before the observations, the participants were made aware of the purpose of our attendance.

2.3.1.3 Participation and attendance

Participant observations are when the researcher serves as the primary instrument for collecting and observing data (Creswell, 2003). This method is appropriate for gathering data on relationships and interactions through recording experience, conversations, and behavior, and suits useful when on-site surveying techniques are inappropriate (Yin, 2014). The purpose of combining participant observations with semi-structured interviews is that it will increase the reliability and quality of the data collection process (Jick, 1979). By performing participant observations, the researchers become more informed about the empirical context and will give the researchers a better understanding of the relations in the studied field (Flick, 2009). It will, in that sense, suit useful when forming the interview guide, as it offers the opportunity to ask questions about things that have been observed (Jick, 1979). Through this method, the researchers can explore, uncover, and describe new behaviors, where the hypothesis or theory is not established a priori.

One of the researchers currently holds a position as an administrative assistant in the network association Lean Construction Norway, and the other researcher holds a membership there. The researchers got exposed to current issues and different viewpoints within the field of Lean construction by attending different network seminars and engaging in conversations with key industry participants. One of the seminars, which was particularly interesting for us to attend, was the seminar "How to get increased productivity in complex building projects using Lean and strategic innovation management" by AF-Gruppen. At this seminar, several representatives from different actors, also Veidekke, came together and shared knowledge and discussed different challenges related to the topic. Furthermore, one of the advisors from Veidekke's headquarters, who currently works with improvement work created a short version of the CP introduction course for us, where he shared their methodology of how they teach and practice CPM. This was very useful as it provided us with a proper introduction and understanding of how the Lean methodology is practiced at Veidekke. We were also invited to present and discuss our findings at the annual meeting of LC-NO, where both members of the network and students from other universities attended. Here we received valuable feedback and opinions regarding our research, and it was confirmed that our field of interest was acknowledged as an important and needed subject to investigate.

2.3.2 Secondary data

Whereas primary data is collected by the researchers themselves, secondary data is originally collected by an external source than the researchers (Bryman & Bell, 2015).

2.3.2.1 Data from Veidekke

For this research, secondary data were mainly collected from Frysjaparken and Hagebyen, this is because these two were the only projects which have conducted the measurements with the same systematic approach. The construction of Frysjaparken started, as mentioned, in January 2018, meaning that the data from 2017 and 2018 were collected before we started our research. We, therefore, gained access to historical data prior to our study, since we were not able to generate quantified data from Frysjaparken. However, as a part of our participation and observation, we were present at several meetings when the data from 2019 were discussed and registered. In order to perform comparative studies on the output and results from the measurements, we also got access to raw and semi-processed data from the already finished project Hagebyen, which were generated by one of the interviewees in our research. Hagebyen was finished in 2014, meaning that the data collected from Hagebyen is entirely secondary data provided to us by Veidekke. The reason for analyzing the data from Hagebyen is that this allows us to crosscheck and compare to see if there are any patterns or similarities in the findings.

The data collected were mainly internal project documents; including project plans, internal guidelines for CP and, raw and semi-processed data on performance measurements such as Percent Planned Completed (PPC). The historical data is highly valuable not only because they provide a holistic view of the process, but also since they present a broader understanding of the rationale behind the performance measurement. Bowen (2009) argues that documentary evidence is often combined with data from observations and interviews to establish credibility and minimize bias. Furthermore, the analysis of the documents is often performed in combination with other qualitative research methods as a means of triangulation. The secondary data were used to analyze the prior effects and results of the PPC-measurements made by the project management at Frysjaparken, and Hagebyen. This was done to reveal important features of the phenomenon in our study, by performing calculations to identify trends and main reasons for deviations by aggregating and analyzing the raw data in Microsoft Office Excel.

2.4 Analytical process

This section outlines the analytical process, which is the baseline for the entire research. This entails description and elaboration of its underpinning methods, such as the development of the theoretical background and data collection, and the data analysis process. As outlined in the research strategy, the interdependencies between each of these methods have been considered by following the scientific approach of systematic combining. The research is based on a continuous interplay between the theoretical and empirical domains, where searching for patterns is a key strategy to provide reliable findings and validity of the results (Dubois & Gadde, 2002).

The iterative process of collecting empirical data from interviews, participation, and observation, categorizing, and refining emerging ideas and connecting them to previous theory and research allowed us to capture the essence from our case study (Bryman & Bell, 2015). Our research process began with building a preliminary theoretical background on Lean Construction and performance measurements as a basis for the data collection process. However, the original framework was then revised and modified along the process as new aspects occurred from our empirical data. This led to the adaptation and expansion of the theoretical background of the fields that were found to be important in order to thoroughly investigate our research questions. An example of this was the informal conditions and effects of performance measurements in Lean Construction, such as awareness of human psychological aspects and soft values, which is considered to play a vital role. We were able to identify aspects that were out of the research scope, and thereby focused on narrowing down to the most significant research areas.

Bowen (2009) states that it is necessary to include multiple sources of evidence for cross verification cross in research. In this research, we collected data through interviews, observations, participation, and document analysis in order to seek convergence and validation through different data sources and methods.

As previously outlined, our research strategy is based on the mixed method, meaning that we integrated both our qualitative and quantitative data in order to gain a breadth and depth understanding of the context. We cleaned and analyzed data from the two projects; Frysjaparken and Hagebyen. The raw data materials from both projects are presented in spreadsheets in Microsoft Office Excel and consist of an overview of the weekly based total planned and finished activities for the whole duration of the project. Based on these numbers, the weekly PPC was calculated with the connected reason for the deviation, which is related to the seven conditions for classifying an activity for feasible (Figure 10). The data allowed us to make a root-cause analysis of the different reasons for the deviation and map the most critical aspects and deviations within the different projects.

Furthermore, we got an overview of the weekly staffing in total for all disciplines. This insight allowed us to make calculations and analyze the "work in progress" and "labor intensity" for every week, on average. However, the most interesting aspect is the analytical process of understanding and discussing the most frequently occurred reasons for deviations. By combining the two research approaches, we were able to gain a more comprehensive and complete understanding of our research questions. As mentioned, there is a potential for biased interpretations with the qualitative research approach. However, our quantitative analysis does not have this weakness, thus by combining the two; the strength of each approach outweighs the weakness of the other.

Quantification in qualitative research can be conducted through a thematic analysis, where the idea is to develop an index of central themes and sub-themes. A theme could be identified depending on the frequency of its occurrence of certain matters, words, phrases, and so on in the course of coding. This process involves sorting, coding, conceptualizing, and categorizing of the collected data, which are then presented in a spreadsheet. An emphasis on repetition is likely to be favored when searching for themes in a corpus of interview transcripts (Bryman & Bell, 2015). However, in this search process, we have identified themes also based on analogies, theory-related material and similarities, and differences in the way the interviewees discuss the given topic (Ryan & Bernard, 2003). This approach allowed us to capture and compare different point of views, thus enriched the discussion section in this thesis. The following table illustrates the identified central themes and sub-themes, including some quotations from our primary data conducted through interviews and observations at Veidekke (Bryman & Bell, 2015). The first main theme reflects upon what and how performance measurements are implemented and used in Veidekke, followed by the motivation for measuring performance, which addresses both the informal conditions and formal structures related to the phenomena. This includes the views and barriers to measuring performance in Lean Construction.

Central Themes	Sub-Themes	Quotations and observations
Motivation for measuring performance in Lean Construction	**Views of performance measurements in Lean Construction**	Our findings indicated that there were different views related to measuring performance, whether it was how it was measured or how it was used. This is illustrated in the following quotations: *"Why should you measure something that has already been done? (..) When you plan something, you try to find what can go wrong, however, with measurements then one has already figured out what has gone wrong" Interviewee # 9* *"The constant transparency of how the project is evolving gives us the opportunity to take actions if necessary." Interviewee # 15* *"It is highly important to measure systematically.(..) We measure, but we do not take the evaluations further with us." Interviewee # 2* *"It is a payment based system on performance, you are being measured all the time." Interviewee # 12* *"There is nothing as important as to have control on productivity, and PPC is quite easy to measure" Interviewee # 2* *"Measurements should not be used to expose someone, it is meant for improving us and how we work." Interviewee # 3* *"It really affects the culture, it will destroy a lot if you have someone who opposes to it." Interviewee# 15* *"The reason that we do not measure PPC is because we are still in the early phases of the project, and think maybe it will be more useful to introduce these type of measurements later in the later project"* - Meeting with the project team 05.03.2019 at Sølvparken *"The PPC measurements does not really interest me." Interviewee # 11*
	Previous knowledge of measuring performance in Lean Construction	*"I have not yet found any tools that can measure it." Interviewee # 3* *"We realize the value of it and are aware of the need, but have not figured how to do it yet." Interviewee # 8* When discussing performance measurements with a field expert in project and performance management at NTNU, it became clear that it is important to understand the meaning behind the numbers: *"The numbers has a story to tell, but in order to be able to express what the numbers actually mean, one has to understand what lies behind these numbers."*
	The time perspective considering performance measurements in Lean Construction	The impression of how much time was dedicated to measuring performance, and which implications performance measurements had on time were the two main concerns. The following statements illustrates this: *"You do not have the time to not do measurements (....) Instead, I just use the numbers to go straight to the point, right away, the idea is that you gain time on doing measurements." Interviewee # 1* *"I don't think you spend much time on the measurements. When you first work on the plan, you just register why you haven't reached the plan." Interviewee # 3* *"One must achieve an advantage of it, if not then time must be prioritized differently." Interviewee # 9* *"I think it will be easier when we get into a better flow, at this stage I do not think it will be useful to make any measurements, or it is quite limited what you will get out of it." Interviewee # 5*

How is performance measured? - Implementation, Learning & Experience	**How is the metrics in the LPS used to measure performance and how is the results used afterwards**	It was interesting to gain insight into, and an understanding of which performance metrics that were used and how the different projects did, or did not adapt to it. Who was responsible to conduct the measurements, and how it was adapted in the on-going project and later into the next project. The following statements illustrates some of these aspects.
		"I think there are many projects that do not have a detailed enough plan. PPC is definitely very good for pushing forward a good plan and then we also get very good data that we can use further. (...) I think that those who do not sit down and spend a good amount of time on it is not prioritizing their time correctly." Interviewee # 10 *"I used the PPC to prioritize which disciplines needed to followed up." Interviewee # 1* *"It is obvious that if you want to implement sanctions against the hired subcontractors, then the numbers are very useful." Interviewee # 1* *"If one does not document it, how should one then share the experiences and knowledge in a reasonable and proper way." Interviewee # 2* *"If the numbers are positive, then we show this to the others. But if not, it would create negativity during the meetings." Interviewee # 10* **Observations like this:** *"It is hard to predict weather conditions. The PPC for concrete is only 34,5% this week, this is due to the fact that there has been a lot of illness among the workers and a lot of snowfall. As a result, we have been spending time shoveling snow and trying to heat up the work area. Meaning that the reason for deviation for this activity is related to external factors, which we are not able to control." – PPC meeting at Frysjaparken 15.02.2019* Illustrates the fact that the reasons for deviations is interpreted differently across the projects, as interviewees at Gartnerkvartalet and Sølvparken argued that they would not devote snowfall to external conditions but rather prior activites since there are actions that should have been taken into consideration at this time of year. *"When looking at the PPC for timber, we see that prior activity was the first reason for deviation, and the look-ahead plan was not readjusted, the workers were, therefore, not able to carry out the tasks according to the plan."* - PPC meeting at Frysjaparken 15.02.2019 *"It could be really useful if one were able to secretly use and remove slack and waste on all the different disciplines and phases." Interviewee # 5*

Implementation issues and informal conditions	**Challenges and implications with performance measurement in Lean Construction**	Here we present some of the quotations regarding the challenges and implications of measuring performance. The following statements give an indication of this.
		"It is important that the numbers are used as indicators, that they actually tell you something. It is not necessarily the case that if the numbers are in a specific way it means that they are good, or that they are bad. They give an indication." Interviewee # 1 *"When you measure what they do, you actually measure how fast they can work. So they can get a feeling that they are not working fast enough." Interviewee # 2* *"After all, there are people who work both "inside and outside", and there are human conditions that form the basis of the execution of most activities." Interviewee # 9* A professor in Organizational Behavior at BI states that prior research shows that; *"When comparing individuals against eachother, it might create a perception of unfairness. On the other hand, when individuals are compared to themselves and their own earlier achievements it will be percieved as less unfair"*

Table 2: Coding of findings - overview of central themes and sub-themes in findings

2.5 Ensuring scientific quality

In order to evaluate the quality of our case study, its trustworthiness and authenticity must be considered (Bryman & Bell, 2015). There are four criteria for assessing the trustworthiness of a study, namely, credibility, transferability, confirmability, and dependability (Lincoln & Gubba, 1985). Credibility and transferability are parallels to the internal and external validity of the research, respectively (Bryman & Bell, 2015; Yin, 2014). According to Bryman & Bell (2015), such an evaluation of business and management research is important to assess the scientific credibility of the case study. Furthermore, one can mitigate the limitations of a case study by, e.g. focusing on the justification of theory building with an explicit statement of theoretical arguments, interviews, and observations that limit informant bias, and presentation of evidence from empirical findings in tables, figures, and appendices (Eisenhart & Graebner, 2007).

Credibility

The credibility of the study is based on whether the collected data is trustworthy, which can be done by questioning the internal consistency (Bryman & Bell, 2015). According to Yin (2014), the validity of the research study is affected by the data collection process. Respondent validation and triangulation techniques were used to ensure high credibility in the research. Combining sources of evidence, while shifting between analysis and interpretation is most commonly known as triangulation (Yin, 2014). The same author postulate that when validating data, the most appropriate system is to count on the notion of triangulation. This method is used to ensure both validity and reliability of the information provided, which involves using more than one research method in the data collection. In other words, it works as a cross verification for investigating the phenomenon from different outlooks. This will make it easier to detect if there is any bias in the data material. Yin (2014) further argues that the advantage is that it provides a more comprehensive understanding of the research question and the information and data collected. Additionally, this will compensate for different weaknesses and strengths of each research method and in that sense, increase the reliability of the results. The different research methods can, therefore, complement each other and help researchers to discover phenomena that would not have been discovered if only one research method had been used.

In this research, a triangulation with mainly interviews, observations, and participation was carried out to ensure credibility and validation (Yin, 2014). These were done according to the theoretical background of some fundamental articles.

Firstly, we developed an interview guide based on our theoretical framework, which includes the opposing beliefs on the topics of interest. Secondly, we aimed to increase the credibility of our findings by comparing the empirical data conducted from our interviews. In this research, we were aware that interview participants could reduce the credibility of the study if they provided us with excessive subjective perceptions. By including a wide variety of participants, we were able to reveal the different perspectives on performance measurements. All interviewees in this research were informed that the recordings would be deleted, and their responses would be anonymous. This was in order to increase their probability for more forthright and open responses, hence, receive more credible answers for our empirical findings. Lastly, our research is also based on document analysis, such as project process plans and other relevant company documents, which is used as documentary evidence in our research (Bowen, 2009). We have included some of these in the appendix (ref. appendix 3), and others are stored in the case protocol.

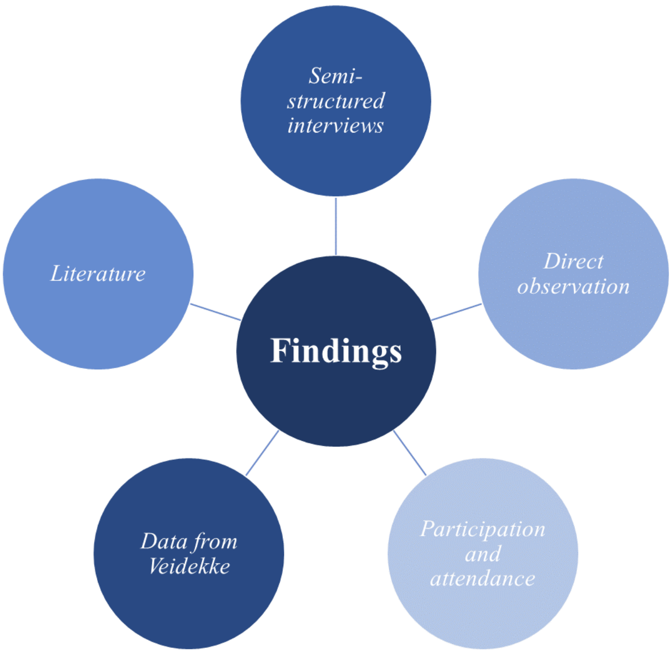


Figure 4: Illustration of our triangulation

Transferability

Transferability relates to whether the findings are relatable to another context or time, which is an important aspect in case studies. According to Bryman and Bell (2015), case studies external validity is dependent upon how easy it is to generalize the findings for other companies and settings, and that several case studies should be compared if any generalizations are to be made (Bryman & Bell, 2015). On the other hand, Halldórsson and Aastrup (2003) claim that researchers should avoid generalizing their findings when conducting a case study, as the results might not be representative of the population. We are aware that the transferability of our findings might not be sufficient for other settings due to the uniqueness of the cases and their complexity. Since some of the findings arguably are firm-specific, the results might only be applicable to similar projects within Veidekke. However, the intention is that some of the findings and discussions might suit useful as a basis for further discussion and research within Lean Construction.

Conformability

It is a concern that researchers act in good faith when the research is carried out. Since researchers take a great part in the case study, they have to act diplomatically and unbiased. In other words, their personal opinions and values should not affect the questions asked, how they act during neither the observations nor how the observations are interpreted (Bryman & Bell, 2015). This was an important part of the process of writing our thesis. Therefore, both of the researchers took field notes individually and participated in all observations, which were later compared when writing a combined summary. During the interviews, both researchers were present to ensure that the interviewees were exposed to any biased thought or asked leading questions. All of the interviews were finished and transcribed before any findings and discussion took place in other to increase the confirmability (Bryman & Bell, 2015).

Dependability

According to Bryman and Bell (2015) research field notes, interview transcripts, secondary data analysis should be stored and secured in an accessible manner, which would enable the researcher to easier present and elaborate the empirical findings. Additionally, by providing thoroughly documentations of the research process, others with a desire to replicate the study will have a better starting point to do so. At the beginning of this research, we applied for approval to carry out interviews and record data according to the new regulations of General Data Protection (GDPR). In order to fulfill the requirements prescribed by GDPR, we have stored all data used for our research in a case protocol locally on one of the author's computer. This was because several of the online storage services, such as Dropbox, do not follow the regulations from NSD, and therefore our transcripts, testimonies, etc. is not safe to store in any place else than locally on a password protected computer. The interview transcripts will, therefore, not be accessible for the public, unfortunately, limiting the transparency of this research. The case protocol will contain transcripts of interviews, the Microsoft Office Excel file with secondary data from Veidekke and summaries from observations at Veidekke.

Authenticity

In addition to the four trustworthiness criteria previously mentioned, Lincoln and Guba (1985) propose an additional criterion of authenticity. This criterion concerns the wider political impact of the research, related to the fairness and ontological-, educative-, catalytic- and tactical-authenticity of the research. First, in terms of fairness, we have included data that represent views of the different stakeholders, from the first-line workers to the project portfolio managers. Secondly, we claim that our research could help the stakeholders at Veidekke to gain a better understanding of their social milieu and to appreciate better the different viewpoints of the other stakeholders. Hence, this research has the potential to receive high ontological- and educative authenticity. Lastly, in terms of catalytic- and tactical authenticity, we hope that the research could act as an impetus to stakeholders who wish to engage and take actions necessary to change their environment and operations.

2.6 Research Limitations

Because of the nature of this study, it is reasonable to believe that there will be limitations regarding the scope of our research. This is much related to the limited time and capacity of a master thesis. We have chosen to include the main aspects of both our theoretical background and the research methodology. The theoretical background was limited to the phenomena this study addresses. Thus, our study does not include all the aspects of performance measurements within Lean Construction.

Our thesis aims to understand the interplay between performance measurements and Lean Construction, but is limited to projects within Veidekke, and, thus, does not capture the overall perspective in the Norwegian construction industry. Our case study has focused on six construction projects at Veidekke in order to get a better overview of the phenomenon of interest. The case study approach is criticized for its ability to be replicated and thereby its limited external validity (Eisenhardt & Graebner, 2007; Yin, 2014). However, we believe that our research has grasped important findings that could be replicable to other Lean Construction projects that seek to measure performance.

Due to time and resource constraints, we limited the scope of the research by mainly focusing on data collected from Veidekke. According to the new regulations regarding the processing of personal data, we decided to keep each interviewee anonymous by both the role and name each participant holds. The regulations, therefore, limit our presentation of empirical findings and discussion, as we are not able to present it in a way that could be possible to identify any of the interviewees.

3. THEORETICAL BACKGROUND

In this chapter, we review and synthesize previous research and literature on relevant topics for our research area. The primary goal here is to compile a strong foundation for our research, and the theoretical background will enable us to identify any potential literature gaps. This thesis will focus on previous research regarding performance measurement and Lean Construction, and the interplay between these two. This in order to reach our research questions on how performance is measured within Lean Construction and why, or why not, performance should be measured in Lean Construction.

The chapter is divided into five main sections. Performance measurement has been a very important topic within the Lean Construction literature, and has over the years been vigorously discussed by several researchers (Ballard & Howell, 2004; Deming, 1968; Fischer, Ashcraft, Khanzode & Reed, 2017; Kalsaas, 2017; Koskela, 1992; Koskela, Ballard, Howell & Tommelein, 2002; Lantelme & Formoso, 1999; Neely, 1999; Star, Russ-Eft, Braverman & Levine, 2016). Therefore, the first section will start with a short introduction to the general understanding of performance measurement before we address the characteristics of performance measurements in the construction industry. The next section presents theories regarding the Lean methodology, followed by a review of Lean Construction set in context with performance measurement. Here we elaborate on the different activities and flows in Lean Construction, value stream mapping (VSM) and the LPS. We also review research concerning the impact of formal and informal challenges and implications for more successful implementation and use of Lean concepts, such as LPS. Lastly, a theoretical framework based on the theoretical findings is presented in the last section.

3.1 Performance Measurement Systems

This section will discuss some of the formal structures related to performance measurements, such as the systems, techniques, and tools used for measuring performance. Performance measurement is a topic without a clear definition in academia, and the understanding of the subject is strongly discussed in research communities (Bititchi, Garengo, Döerfler & Nadurupati, 2012; Goshu & Kitaw, 2017; Neely, 1999; Neely, Gregory & Patts, 1995). However, regardless of the various views on the subject, the performance of organizations has always exerted considerable influence on the actions of companies (Folan & Browne, 2005). Consequently, the means and ways of measuring performance accurately are considered as an increasingly important area of research for both academia and organizations (Fischer et al., 2017; Hoque, 2008; Marr & Schiuma, 2003; Neely, 1999; Try & Radnor, 2007).

3.1.1 Performance measurement in general

Performance measurement is viewed as a critical management tool that can help to determine failure or success in both functional and organizational performance. It can be defined as the process of quantifying the effectiveness and efficiency of past actions (Neely, 1999), where the goal is to satisfy customers with superior effectiveness and efficiency (Neely et al., 1995; Neely, Adams & Kennerly, 2002). Effectiveness is here defined as the extent to which a specific goal is reached with the given resources applied, while efficiency is defined as how economically resources are utilized in order to meet the requirements from the client (Cheng, Tsai & Lai, 2009; Neely et al., 1996).

Rose (1995) claims that measurement can identify stagnation or shortfalls and guide steady advancement toward established goals. In other words, the author states that performance measurement will provide a sense of where we are and where we are heading. If used properly, performance measurement helps to create feedback on the effectiveness of improvement interventions as part of the development and learning for the management (Cohen & Levinthal, 1990; Liebowitz, 2004). The process of performance measurement is usually determined by a number of indicators and has evolved from producing merely accounting-related information to more comprehensive information including both financial and non-financial indicators (Yang, Yeung, Chan, Chiang & Chan, 2010).

In general, the performance measurement systems consist of processes, mechanisms and different criteria of areas of performance, and needs to be aligned with organizational policies, objectives and missions (Dixon, Nanni & Vollman, 1990; Gündüz, 2015; Kaplan & Norton, 1996; Kaplan & Norton, 2004; Neely et al, 2002; Pongatichat & Johnston, 2008; Sink & Tuttle, 1989). In addition to improving strategic control, there are two main reasons often mentioned for why managers should measure performance; to influence the behavior of people and to identify potential areas for improvement (Beatham, Anumba, Thorpe & Hedges, 2004; Robinson, Anumba, Carrillo & Al-Ghassani, 2005). “Measures send people messages about what matters and how they should behave” (Neely et al., 2002, p. 9). A result of using systems for performance evaluation is that it will affect future decisions and actions, independently of the main purpose.

Performance measurement provides the information that is required for obtaining process control and enables the opportunity to develop challenging goals (Lantelme & Formoso, 2000; Moon, Yu & Kim, 2007). Moreover, several researchers argue that by developing and implementing a balanced set of measures, business performance can be enhanced (Kaplan & Norton, 1992; Neely et al., 1996; Neely et al., 2002). Behn (2003) claims that organizations, especially in the private sector, have a great focus on measuring performance. He further argues that it is neither the act of measuring nor the resulting data which will generate results, but only when the measures and data are utilized effectively that they will produce satisfactory results.

3.1.2 Performance measurement in the construction industry

Performance measurement has been implemented in several sectors to drive improvements in productivity. In construction organizations, performance tends to be measured in terms of quality, cost, and time (Kagioglou, Cooper & Aouad, 2001; Ward, Curtis & Chapman, 1991). However, there seems to be no consensus amongst industry researchers about how to best study the productivity performance in construction projects, despite the existence of well-developed frameworks (Crawford & Vogl, 2006).

The construction industry is a unique industry, and operational experience is an important factor in maintaining high levels of productivity (Dozzi, Eng & AbouRizk, 1993; Song & AbouRizk, 2008). Performance measurements can provide additional information and overview of project progress and can thus create a basis for progressive improvement through root-cause analysis, which can enhance opportunities for an increase in efficiency and quality. Such identification should be carried out by the immediate manager or those responsible for the plan (Ballard, 2000; Wegelius-Lehtonen, 2001). Leong and Tilley (2008) argue that without using appropriate performance measurement systems, it will become challenging for organizations to understand how to achieve improvement or why poor performance continues. In addition, it will be challenging to understand whether the intended objective and goals will be achieved or not (Neely et al., 1996).

As mentioned in the introduction of this thesis, prior research has emphasized that productivity, or the lack thereof, has been a major challenge facing the construction industry for the last decade (Barbosa et al., 2017b). The construction industry has made several attempts to establish common metrics for measuring how productivity increases or decreases over time, but this is still not used in a systematic or consistent matter during the project (Langlo & Andersen, 2016). Today, productivity is viewed as the main indicator for performance in the construction industry and can be defined as a measurement of how efficiently inputs are used to produce outputs. This is different from performance, which measures how well the project achieves its intended goal or purpose (Page & Norman, 2014). As such, productivity can be said to describe the potential output of a production process given its input factors (Crawford & Vogl, 2006).

Managing site-related issues are often difficult and complex in construction projects, and one of the main challenges is the quantification of all factors involved on site. Therefore, Dozzi et al., (1993) claimed that the most accurate measure of productivity that can be used in construction projects is the number of units produced per person-hour consumed or the number of person-hours consumed per unit produced. Projects in the construction industry often consist of labor-intensive processes, and labor is, in absolute terms, the only resource that is productive. Thus, it depends greatly on human performance (Jergeas, Chishty & Leitner, 2000; Laufer & Jenkins, 1982).

This view on productivity has been questioned by other scholars. For example, Flanagan, Cattell, and Jewell (2005) argue that measures of productivity do not adequately take into account the impact of factor substitution or technical change and that productivity measures become inadequate because they do not consider value-adding factors such as quality, innovations, and the effectiveness of management. Crawford and Vogl (2006) discuss in their research that it is possible to outline a framework that aims to avoid these limitations. Furthermore, they define single factor productivity measures, such as the average labor productivity (ALP), as the potential output of a production process based on the given inputs. These types of measures focus on the impact of one-factor input and are relatively easy to measure. However, economists tend to prefer estimating multi-factor productivity, or total factor productivity, which can capture the interaction between factors and allow for a more in-depth analysis of productivity (Crawford & Vogl, 2006). However, the authors emphasize that, in practice, performance measurement analysis tends to use both multi and single factor measures. As such, ALP can be used as a first approximation, and for deeper and more detailed analysis of the underlying factors, measures that are more sophisticated could be employed. Measurements on labor productivity can provide useful information for estimating purposes and scheduling future projects (Alinaitwe, Mwakali & Hansson, 2007). According to Strandberg and Josephson's research in 2005, less than 20% of the construction workers time is being spent directly on value-adding activities.

3.2 Lean Construction

This section will first present a short introduction of the Lean methodology, then a description of how Lean is interpreted in the construction industry, followed by an explanation of the different activities and flows in Lean Construction. Lastly, we will elaborate on the role of value stream mapping in Lean Construction.

3.2.1 The Lean Methodology

The roots of the Lean methodology started in Japan, more specific at the car automaker Toyota, which is credited as the founder of Lean production with its Toyota Production System (TPS) (refer to Appendix 1). There is still no common understanding of what Lean is and how it should be interpreted among researchers (Alves, Milberg & Walsh, 2012; Jørgensen & Emmitt, 2008; Pettersen, 2009), but Womack, Jones, and Roos (1990) defined the equation:

Lean = Purpose + Process + People

This equation shows the main elements in the Lean philosophy, which must be considered simultaneously, and they identified the "perfect process" in which each step should be valuable, capable, accessible, and adequate. In general, the application of the Lean principles basically involves working continuously toward identifying and eliminating waste from processes with the ambition of obtaining only value-adding activities in the value stream (Rother & Shook, 2009). A natural consequence of Lean is a focus on reducing costs, but it is important to note that this is not the main purpose of the concept. It is a misconception that Lean primarily is about employing various tools to reduce costs. Instead, the tools should help to implement the underlying concepts and principles of Lean, with one of the main goals being to increase the capacity by designing a system that optimally meets customer demand (Fischer et al., 2017; Womack & Jones, 2003).

In 2003, Womack and Jones released the second edition of the book "Lean Thinking" where they discuss and describe the most important principles in the Lean philosophy. The overall goal is to maximize quality and customer value, while at the same time eliminating sources of waste. According to the authors, the five main principles are:

1. *Define and identify customer value as seen from the customer's perspective*
2. *Understand, map and optimize the value stream*
3. *Create value process flow*
4. *Establish Pull*
5. *Strive and seek perfection* (Womack, Jones & Roos, 1996, p.10)

This process is called Kaizen, which can be translated as continuous improvement (Womack, Jones & Roos, 2007). The authors argue that companies go through four stages, from beginner to cutting-edge, where they will gradually discover an improvement potential within the organization.

3.2.2 Lean in the construction industry

Lauri Koskela (1992) developed comparable principles for construction processes, which is focused on continuous improvements. In 2004, Koskela wrote the article "Moving on beyond Lean thinking," where he discussed the work of Womack and Jones (2003), and questioned the way Womack and Jones portray the five principles as a fundamental part of the Lean philosophy. Although being compact and intuitive, Koskela argues that the five principles only reflect a small part of the philosophy. Through their studies, Womack et al. (2007) conclude that the previously mentioned five principles do not fulfill the criteria that should be required for it to be described as a perfect production theory. Instead, the principles are general and intended to be applicable on a universal level, across different industries and sectors; “We believe that the fundamental ideas of lean production are universal – applicable anywhere by anyone” (Womack et al., 1990, p.9). Koskela (1992) on the other hand chose to focus only at the construction industry (Helland & Skjelbred, 2014), and we will, therefore, base our thesis on Koskela’s principles in our understanding of Lean Construction.

As the Lean practices originated in the manufacturing industry, it is important to clarify and define how Lean can be adapted to the construction industry. This is necessary in order to get a proper understanding of what can be expected from the interpretations and methods used by construction companies. In 1992, Lauri Koskela challenged the traditional construction industry by introducing the “new production-philosophy,” which he named Lean Construction (Ballard & Howell, 2003). This is not a replica of the Lean manufacturing system, but rather a methodology inspired by the principles and concepts of the TPS, which is adapted to the construction industry (Kalsaas, 2017; Sacks, Koskela, Dave & Owen, 2010). Lean Construction includes a great variety in different principles, methods, tools and objectives, and a vast diversity in the application and interpretation of the concept (Alves et al., 2012; Green & May, 2005; Jørgensen & Emmitt, 2008). The principles include a distinct set of objectives and clear guidance for implementations from the beginning to the end of the project, all aimed at maximizing the performance and productivity throughout the project (Ballard & Howell, 2003).

Moreover, during the past two decades, Lean Construction has grown in prominence from being one of the most appropriate initiatives to improve performance, to be considered one of the primary performative improvement initiatives in the construction industry (Egan, 1998; Sage et al., 2012). Although the Lean philosophy has been experimented with in construction projects for a while, there is little coherence on the means and ways of implementing Lean Construction (Alves et al., 2012). Additionally, there are still few studies that provide a thorough review of the outcomes. However, what seems clear is that the interpretation of Lean has primarily been focused on implementing formal structures such as specific systems, tools and techniques, rather than the whole business philosophy (Alves et al., 2012; Green & May, 2005; Jørgensen & Emmitt, 2008; Sage et al., 2012; Saurin, Rooke & Koskela, 2013). An important distinction to note, which separates production in the construction industry from other types industries, is that in the construction industry the production is moved to the product and the production runs through the product, while in other industries it is typically the other way around (Kalsaas, 2017). This feature can lead to sub-optimized workflows. If all workstation mainly focuses on their part of the project and none of the workstations have a full overview of the entire process, it is easy to create projects in which each workstation is optimized but not the overall project (Modig & Åhlstrøm, 2018). With Lean thinking, the focus is on optimizing the project in its entirety, rather than having each worker solely concentrates on optimizing their own part in the project. Therefore, Howell (1999) argues that if all work together towards a common goal, the result of the project can be greater.

3.2.3 Activities and flows in Lean Construction

In the construction industry, one can differentiate between waste, non-value adding activities, and value-adding activities. Modig & Åhlstrøm (2018) discuss in their book, *This is Lean*, the efficiency paradox, arguing that companies often allocate a significant amount of time and resources on waste and non-value adding activities. In other words, focus on high capacity utilization tends to increase the amount of work and thereby decreases flow efficiency. The high focus on resource efficiency, rather than flow efficiency can create negative effects, which will be further discussed in the following.

Waste

Bertelsen (2003) argues that the construction industry has several similarities with the manufacturing industry, like for instance the seven sources of waste that find place in any construction projects, such as transport, inventory, waiting, and defects. These types of waste inhibit the construction projects performance because resources get delegated to activities that do not add value to the project (Bertelsen, 2003). Due to this, there is an increasing emphasis on searching for ways to minimize, or preferably, eliminate these sources of waste. Some researchers suggest that the focus should be on increasing standardization and systematization in any given situations that might occur on the construction site, thereby reducing the need for the sources of waste. In this way, the systems become less complex and more similar to the traditional production system in the industry, which makes it easier to adopt the ideas from the Lean philosophy (Barbosa et al., 2017). Due to unpredictable workloads and availability of resources, the excessive attention towards activities, which is typical of the construction industry today, results in neglecting the waste that is being generated between the ongoing activities. In other words, this means that the old method of project management and production tends to prioritize activities rather than flow and value-creation.

On the other hand, Lean Construction aims to optimize the flow between all of these activities (Howell, 1999; Kalsaas, 2013; Koskela, 1992). Howell (1999) further explains that minimizing the interaction between the activities, that is, the combined effect between the dependency and variation between them, is important if the purpose is to fulfill projects as fast as possible. This could be of special importance when the project is of great complexity. As a starting point, an important aspect of Lean Construction should, therefore, be to understand the effect of dependency, the variety of activities along the value chain, and the physical circumstances for production. Modig and Åhlstrøm (2018) define this as a chain of cause-and-effect, where a primary need might cause secondary needs as a consequence of mainly focusing on high resource efficiency rather than flow efficiency. As a result, several problems will emerge, which will then require new resources and activities.

Kalsaas (2013) states that one can distinguish between observable and hidden waste in the construction industry. In the same research, he measures waste and categorizes them into six categories. Firstly, time spent to clear up the area to get access to the workspace. Secondly, extra work that might occur due to inaccuracies, e.g., when prefabricated parts do not correctly fit. Thirdly, time spent searching for materials, tools, and/or team members. Fourthly, unutilized or idle time, a category which could be hard to measure since an extra effort to finish a task early might result in some idle time at the end of the day, which in itself is not a bad thing. The fifth category is defined as correcting, and the final category is the amount of time spent waiting for materials, preceding activities, weather-dependent activities, and/or inaccessible workplace. Four key factors need to be addressed in order to reduce time and effort used on these waste categories (Koskela, 1992). First, there must be a commitment by the management team in order to improve every activity in the organization, and, secondly, involvement amongst the employees, where they are able to take responsibility and control their process. He further suggests that, thirdly, there should be a focus on measurable improvements, although implementation of such measurements could, lastly, require a substantial amount of learning as well.

Non-value adding activities

The production process consists of a flow of material and information and can be divided into several activities such as production, inspecting, moving, and waiting (Koskela, 1992). Out of these, only the actual production will contribute to value creation (Koskela, 2000). Both Koskela (1992) and Liker (2008) claim that the non-value adding activities, such as accidents, time spent correcting mistakes and waiting time, should be minimized and is just as important as any other sources of waste. However, Jørgensen and Emmitt (2008) argue that there are some non-value adding activities that are essential and should, therefore, not be treated as waste. Planning is an example of this, as it provides internal value through minimizing sources of non-value adding activities and waste while improving the project execution processes (Gao & Low, 2013; Kalsaas, 2017). This illustrates the need to implement some non-value adding activities in order to apply Lean thinking.

The focus on resource efficiency prevents flow efficiency, and thereby the ability to eliminate waste. Organizations that focus on flow efficiency ensures that handovers between each discipline are smooth. This will result in a continuous flow where the disciplines are able to acknowledge and take responsibility for the whole project process. Thus, by not focusing on resource utilization, it will be possible to spare some resources. Lean thinking could, therefore, be one way to solve the efficiency paradox in the construction industry as it involves a greater focus on flow in the project. Where the distinct disciplines get a comprehensive understanding of the whole picture instead of thinking in silos (Modig & Åhlstrøm, 2018).

Value-adding activities

The concept of value in Lean Construction is mainly associated with product delivery and with parameters such as quality, cost, and time. Value could be interpreted as an ambiguous concept due to different interpretations of the term over the years (Salvatierra-Garrido & Pasquire, 2011). According to Lindfors (2000), value is the reason that something increases its profit and quality while decreasing time and cost, but also covering customer needs. Emmitt, Sander, and Christoffersen (2005) grouped value into external and internal values, i.e., value for the customer and value for the participant of the delivery team. However, "*a fundamental goal of Lean Construction is to aid in the delivery of external value by managing the internal value generation process*" (Björnfot & Stehn, 2007, p. 35).

Value-adding activities are activities that add value to the customer and which the customer is willing to pay for, according to Lean thinking (Ballard & Howell, 2004). The value created in an activity or a process is viewed as a contribution to the overall project value (Koskela, 1992). This view was later described in a "transformation flow in value generation" model by Koskela (2000), where he focused on managing the three concepts of production simultaneously: transforming the project through value-adding activities, creating flow through non-value adding activities, and managing value generation according to the customer needs. Each of these concepts focuses on production progress from a Lean Construction view, which can resemble value stream mapping, which will later be discussed in the following subsection.

3.2.4 Value Stream Mapping

During the past few decades, several concepts have been developed based on the Lean philosophy to reduce waste and increase value creation. Some of these concepts, such as Just-in-time delivery (JIT), pull - or phase scheduling and value stream mapping (VSM), focuses on reducing lead-time, controlling and managing workflow, and continuous learning (Ballard & Howell, 2004). Research has shown that reliable plans need to be in place in order to increase performance in the construction industry (Ballard, Hamzeh & Tommelein, 2007; Liu et al, 2011). VSM could be used as a tool to show how the different actions are carried out in the process from the very beginning to the end. It is also a way to detect value-adding and non-value adding activities in both production and design processes, as it provides a basis to understand and map the information and material flow starting through the entire organization (George, 2002; Rother & Shook, 2009).

The ultimate goal of VSM is to identify and try to eliminate all sorts of waste in the value stream (Rother & Shook, 2009). The production management, which requires an active sense of control, could perhaps be improved by more predictable workflow and less uncertainty in the production plans (Howell & Koskela, 2000). Another important aspect of VSM is that each discipline does not just optimize their process, but rather aims to improve the entire production process. This will make the flow in the process more transparent for the whole organization (Rother & Shook, 2009).

According to Rother and Shook (2009), there are generally three steps in creating a value stream map:

1. A current State Map that begins with a flow chart showing the progression of a process from its start to the end. This map serves as a basis to get an overview of non-value adding activities and suggest improvement towards Future State Map.
2. An ideal State Map is a flow chart illustrating the optimal end product where the goal is to minimize the level of waste and non-value adding activities.
3. Future State Map shows the flow of information after executing the improvements from the Current State Map by finding solutions and eliminating waste. This map needs to be updated regularly due to its importance for deadlines and reach towards the Ideal State.

Olhager (2011) states that a drawback of VSM is that it does not work optimally for sophisticated value streams, such as in the construction industry. This is because of the complicated production and process structures, and that only basic Lean principle and tools are used for developing Lean flow. However, researchers argue that VSM can be implemented in construction projects to gain an improved Lean tool and organizational change towards a Lean culture (Barathwaj, Singh & Gunarani, 2017; Björnfot, Bildsten, Erikshammar, Haller & Simonsson, 2011; Simonsson, Björnfot, Erikshammar & Olofsson, 2012).

3.2.5 The Last Planner System

The LPS has been actively in use for approximately two decades, although the basic structure has not seen any major changes, the way it is implemented has in fact gradually evolved (Macomber, Howell & Reed, 2005). The LPS was developed by Glenn Ballard (2000) and Greg Howell (1999) with the goal of being a system for control assisting and production planning. LPS is best described as a system or mechanism for transforming the work that should be done, into only the work that can be done, also referred to as pull scheduling. The LPS also follows other Lean construction principles such as VSM and JIT (Ballard, 2000; Ballard & Howell, 2004; Porwal et al., 2010). Trough pull scheduling, activities are certain to be on the correct path even before they start, as project managers are forced to focus on coordination and communication between the project parties. This makes it easier to monitor activities while they are in progress, but also to report and keep tracks of the development while forecasting for the future (Laufer & Tucker, 1987; Kalsaas, 2017). As previously mentioned, the construction industry is often characterized by a great variety and change in the flow upstream in production. A central feature behind the LPS and Lean Construction is to work towards reducing possible disturbances and obstacles before production takes place. Moreover, the LPS primarily focus on how to strive for predictable flow in the production and improve the involvement of the project participants through collaborative planning (Ballard, 2000; Koskela et al., 2002).

The LPS structure enables craftsmen to be more involved in planning their own working process from the early phases in the planning of the project. This is an underlying principle in LPS as it aims to give the involved participants a responsibility to ensure satisfactory quality of the delivered assignments. The involvement should also be implemented horizontally between the project managers and performing contractors (Ballard, 2000; Kalsaas, 2017), which is also supported by Macomber and Howell (2003) who argue that the participants should be responsible for evaluating how the organization collectively performs in the projects. The method aims to perform with a high degree of reliability and predictability through mutual adaptation and assumes that managers from the different disciplines have the best information about their activities. In that way, they are able to contribute with their knowledge and experience, but also the prerequisites for removing unnecessary uncertainties in continuous phase-plan meetings. The approach of LPS is to include a measurement of the planning systems performance, which is considered an important component for further improvement of the planning process. However, there are few projects that are able to exploit all of the benefits from LPS, but even partial implementation can provide substantial improvements (Ballard & Howell, 2004; Fosse & Ballard, 2016).

The LPS has been defined by the Lean Construction Institute as a "production planning system designed to produce predictable workflow and rapid learning in programming, design, construction, and commissioning of projects" (Lean Enterprise Institute, 2018). After the introduction of the LPS, construction projects tend to have a more predictable workflow, a reliable plan and a noticeable improvement in production performance (Ballard & Howell, 1994b; Ballard & Howell, 2004; Ballard et al., 2007; González, Alarcón & Mundaca, 2008; Kalsaas, 2017; Tommelein & Ballard, 1997). Sacks and Harel (2006) revealed that subcontractors were more likely to devote resources into projects where they were involved early in the planning phase, as opposed to projects that were perceived as more unpredictable.

The system enables learning from failures in the planning process by identifying the main cause for the failures and implementing preventive measures to prevent them from happening again (Ballard, 2000; Ballard et al., 2009; Fosse & Ballard, 2016). As a part of defining the purpose of LPS, Koskela et al. (2010) describes the process of implementing the systems as consisting of five steps; master scheduling, phase scheduling, lookahead planning, commitment, and weekly work planning, and finally learning.

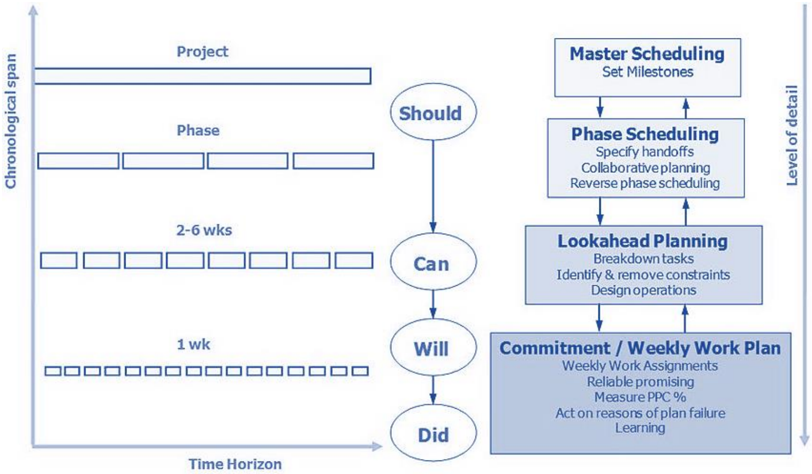


Figure 5: Planning stages in the LPS for production planning and control (adopted from Ballard 2000)

Master scheduling summarizes, in abstract terms, the work that should be done and highlights major milestones in the project. Phase planning breaks down the milestones into smaller phases and is used to coordinate actions which extend beyond the lookahead perspective. This step aims towards minimizing unnecessary accumulation of work in progress. The lookahead plan breaks the phases into tasks, where it is important to evaluate the state of the preconditions for the tasks and to work toward eliminating constraints. This stage should represent a time frame of roughly two to six weeks. Commitment planning is the stage where the most detailed planning finds place and results in commitments to deliver work that is placed in the weekly work plan (WWP) (Ballard, 2000; Tommelein & Ballard, 1997). Commitment planning is usually carried out during a meeting outside the standard WWP meetings and should be done in consultation with the last planners. This is where all parties negotiate to achieve a feasible and reasonable plan to which all parties can commit. This method avoids tasks and assignments that "should" be done according to master and lookahead plans, but still include unresolved constraints. In the last step, "Learning," the organization monitors the execution and report the "percent plan complete" in order achieve continuous improvement and to learn from failures related to planning (Ballard 2000; Ballard et al. 2009; Koskela et al. 2010). The system helps to increase the reliability of weekly work planning by connecting the master or phase schedule properly to the WWP through lookahead planning. Ballard (1993) argues in his research that in order to achieve control over work processes, the last planner should be identified. The last planner is defined as the individual who is responsible for task commitments and ensuring that the final assignment of work is available for the given discipline. This last planner is typically the foremen and superintendents for the different disciplines (Aslesen & Tommelein, 2016; Ballard & Howell, 1994b). In their study, Aslesen and Tommelein (2016) discuss the role of the last planner and define four different types of planning behavioral patterns, they argue that the communication skills, judgments, and choices made by the last planner strongly influence the project plans. Accordingly, planning is not only about issuing directives, it is also about social and human dynamics.

3.3 Performance measurement in Lean Construction

Performance measurement and Lean Construction has independently been presented in the prior chapters. In this chapter, we will further investigate how Lean Construction has been incorporated to solve productivity issues by integrating performance measurement metrics in construction projects.

3.3.1 The role of performance measurement in Lean Construction

Performance measurement is currently not highlighted within the Lean concept, and there seems to be a literature gap in the field of Lean Construction, in particular with respect to discussing the purpose or necessity of measuring performance and productivity in construction projects (although there are some exceptions). The focus on implementing Lean without much emphasis on performance measuring appears to be common in the literature. In 1990, Womack et al. performed one of the biggest benchmarking studies, comparing the performance of automotive companies in respectively the USA, Europe, and Japan. In later research, Womack and Jones (1996, 2007) concluded that performance measurement and comparisons are not worthwhile doing. Instead, they argue that companies should focus on improving performance and process by implementing Lean techniques. In 1986, Deming discussed the impact of performance measurement on the effectiveness of management and the sustainability on continuous improvement and discussed the difficultness of managing these without measuring performance. On the other hand, Lantelme and Formoso (1999) state that in the theoretical framework of Lean Construction, performance measurement plays an important role in terms of providing necessary process transparency. It helps the workers see how they are performing as it highlights attributes that usually are invisible, and in that sense, it creates conditions for decentralized control to be implemented. Moreover, research indicates that performance measurement could be used as a systematic way of judging project performance (Forsberg & Saukkoriipi, 2007; Star et al., 2016).

3.3.2 Performance measurement in the Last Planner System

Over the years, various types of formal structures and approaches have been used within the construction industry. In this thesis, we will mainly focus on the LPS and the most common measurement metrics; percent planned complete (PPC), tasks anticipated (TA), and tasks made ready (TMR) (Fischer et al., 2017; Hamzeh, Zankul & Rouhana, 2015a). By carefully evaluating these metrics, project managers are able to simplify the work to track uncertainty and take corrective action (Hamzeh, Saab, Tommelein & Ballard, 2015b; Fosse & Ballard, 2016). Ballard (2000) defined PPC as the number of planned activities completed, divided by the total number of planned activities. According to Ballard and Howell (1994b), measuring this percentage can contribute to improvement in planning trough identifying reasons for non-completion with root-cause analysis and thereby prevent repetitions of these. Hence, PPC is being used as a control metric in the LPS as it measures the reliability of work plans (Ballard & Howell, 1994a; Ballard, 2000; Knotten & Svalestuen, 2014). In their study Liu, Ballard and Ibbs (2011) were not able to prove that productivity could be improved by carrying out as many activities as possible. Instead, this study concluded that the key to increased productivity lies in having more predictable plans, which was also proven in an earlier study by Ballard and Howell (1994a,b).

Lookahead planning is considered the first step in production planning. It focuses on making tasks ready in the sequence and pace needed to finish the project on time while matching the workload with the available capacity and resources. Through a work breakdown structure, one can increase the reliability of construction workflow by designing operations, assign responsibilities, and removing barriers for each activity. TA is used to measure the success of this planning by measuring the number of correctly anticipated tasks in the project. The study conducted by Hamzeh et al., (2015b) has proven that changes in TA have a positive impact on reducing the project duration. TMR measures the ability of lookahead planning in identifying and eliminating constraints to make activities ready for execution (Ballard, 1997; Hamzeh et al., 2015a; Hamzeh, Zankoul & El Sakka, 2016). The TMR has so far only been studied in relation to its impact on PPC and not the whole lookahead process (Hamzeh et al., 2015a).

The LPS metrics are indicators in an attempt to identify patterns regarding the project progress and the reliability of planning. They do not describe the more traditional parameters such as quality, cost, or time (Takim, Akintola & Kelly, 2003; Star et al., 2016). The degree of Lean concepts implemented in projects, such as LPS, can vary in practice, but even partial implementations have been shown to have a material positive impact on performance (Ballard & Howell, 2003). In their study, Liu et al. (2011) have proved that there is a significant positive correlation between measuring PPC and productivity. However, although PPC could improve labor productivity, Ballard and Tommelein (2016) claimed in their research that even a PPC of 100% did not guarantee that the project would not fall behind schedule. The project progress and PPC only correlate properly when activities are made ready in the appropriate sequence and rate. Therefore, a lookahead planning process should be applied to the LPS so that activities can be completed when needed.

However, regardless of the suitability of the metrics used to measure performance in Lean Construction, prior research highlight that there are both challenges and barriers related to both formal structures and informal conditions that need to be addressed when implementing new systems and tools, both on the project and industry level (Porwal et al., 2010).

3.4 Challenges and implications of measuring performance in Lean Construction

This section will elaborate on some of the main aspects that influence the process of implementing Lean and formal structures, such as systems and tools in the construction industry, and issues that might occur when measuring performance in Lean. This is followed by a discussion around the informal challenges and implications of measuring performance in Lean Construction.

3.4.1 Challenges and implications related to formal structures

In addition to a general lack of quantitative case studies on the effects of using Lean in construction projects, there is currently no common definition of Lean (as briefly discussed in section 3.2.1) (Alves et al., 2012; Modig & Åhlstrøm, 2018). Researchers have also suggested that Lean might be a passing trend, seeing as it has not yet been thoroughly established (Alves et al., 2012). According to Koskela (2000), the potential benefits from Lean thinking concepts are difficult to define and measure, as the terminology appears to be vague and confusing. Researchers have in general concluded that Lean is useful in complex processes and, as a result, Lean tools, techniques, and concepts have been highly promoted over the years in the construction industry (Ballard & Howell, 2004; Ballard, Tommelein, Koskela

& Howell, 2002; Barbosa et al., 2017a; Daniel et al., 2017; Kalsaas, 2017; Knotten & Svalestuen, 2014; Porwal et al., 2010) However, research also shows that there are some critical aspects that need to be considered when implementing the Lean methodology into construction projects (Green & May, 2005; Jørgensen & Emmitt, 2008; Koskela, 2000; Porwal et al., 2010), and several Lean Construction institutes have been founded around the world, such as LC-NO in Norway, to discuss and promote the Lean philosophy and its applications into the construction industry.

Lean Construction uses many of the same tools and methods as Lean manufacturing (Womack et al., 2007). However, a construction project is a very complicated production system compared to, for example, an assembly line (Saurin et al., 2013), and so some adjustments are required. In each construction project, a unique "product" will be produced in a complex setting, which is significantly different from the production process of a single product in an assembly line. Every construction project could, therefore, be viewed as a "prototype" (in other words, a type of project that is executed only once), and in that sense there are some unique aspects that need to be addressed when implementing the Lean concepts in the construction industry (Jørgensen & Emmitt, 2008; Koskela, 2000). These aspects include risks and uncertainties related to internal and external factors that are difficult to forecast accurately, like for example geotechnical risks or uncertainties related to manning, and thus affects how new systems and tools are integrated in the organization (Ballard & Howell, 1994b; Ballard, Kim, Jang & Liu, 2007; Barbosa et al., 2017a). Therefore, Porwal et al. (2010) argued that Lean tools and concepts, such as LPS, should be implemented within the entire production process. Moreover, they also stated that partial implementation is one of the challenges faced during the use of LPS. Accordingly, prior research emphasize that in order to ensure successful implementation, the key principles of Lean Construction must be accompanied by a consistent strategy for the process of implementation, whereas every actor is actively involved and participate in the activities toward implementing the Lean tools and techniques (Mossman, 2009; Sage et al., 2012).

Implementation issues and barriers at both the project and industry level has been studied by several researchers, with focus on identifying how the Lean elements are interpreted and used (Alves et al., 2012; Eriksson, 2010; Sage et al., 2012). In their research, Porwal et al. (2010) identify twelve different challenges faced by construction professionals, classified into two categories: (1) challenges during implementation of LPS, and (2) challenges during the use of LPS. Moreover, they conclude that the development of LPS implementation strategies and training are important prerequisites for achieving successful implementation and use of LPS. This is also important to be aware of when implementing tools and techniques for measuring performance, since a lack of leadership, commitment, training, and understanding of new systems hampers the beneficial outcomes of the measurements. Additionally, there could be contractual challenges and disagreements when implementing LPS and systems for measuring performance, as subcontractors could oppose the practice. This could be due to a lack of prior experience or understanding or fear of being exposed (Ashton, Fagan & Cook, 1990; Bernstein, 2012; Powell, 2004).

Managers in the construction industry tend to rely more on their experience and intuition when it comes to problem solving and decision-making, instead of a structured set of data and tools to understand the problem (Lantelme & Formoso, 1999). In 2004, Sarah Powell performed an interview with Andy Neely, professor of Operations Strategy and Performance at Cambridge University, discussing, among other things, the challenges of performance measurement. He claimed that in the 1990s, there was a tendency to measure things that were easy to measure, which often meant measuring the wrong things. However, this has changed, and now, the problem is excessive measurement (Powell, 2004). Neely further argued that there are four fundamental processes of performance measurement, which all pose different challenges: measurement system design, implementation, managing through measurement, and updating the measurement system. Concerning the design process, the challenge lies within choosing the right metrics for measuring, and Neely argues that the outcome often is that companies just try to quantify everything (Powell, 2004). As presented in section 3.3.2, there are several metrics which could be used to measure performance. However, Chew (1988) argues that the use of a single factor metric could be misleading, as workers and managers then may find it challenging to get the overall picture and they will thereby not be able to use it in their decisions and priorities. Instead, one should strive to achieve a multi-factor perspective, and one way of doing this is using multiple single-factor metrics and combining them. This procedure could help to identify the underlying causes of changes in productivity much easier (Crawford & Vogl, 2006).

Accordingly, single metrics should be considered as a part of a more extensive multi-factor metrics system. Therefore, by combining LPS metrics such as PPC, TA, and TMR, one will get a better indication of how the company's overall productivity could change with changes in these metrics.

For more complex systems like the ones we find in construction projects, one should also consider additional characteristics like the dynamic relationships and coordination between many disciplines and stakeholders. In other words, construction projects can be viewed as a “socio-technical” system where collaboration between the technical and social aspects plays an important role (Green & May, 2005). There is little repetition in activities and processes between projects, as there are variations or modifications in both aspects for every construction project. However, trough detailed planning, stakeholders can adjust and reduce the complexity (Forbes & Ahmed, 2011), and the Lean principles can also be adapted and implemented into such complex production systems (Saurin et al., 2013).

In sum, prior research emphasizes that appropriate structures and tools are necessary and important when implementing new systems and innovations, such as performance measurement in Lean Construction, as they help to create coherence and control (Bygballe et al., 2018; Tzortzopoulos, Sexton & Cooper, 2005). However, several researchers have urged the need to not only focus on formal tools and techniques but also acknowledge the impact of informal conditions and socio-cultural context which might influence the implementation (Bygballe et al., 2018; Green & May, 2005; Sage et al., 2012). For example, in their study, Sage et al., (2012) found that the informal mechanisms played just as an important role as the more formal mechanisms. Attention must, therefore, also be given to informal conditions and implications, in order to create an understanding of what it takes to implement Lean Construction and performance measurements successfully.

3.4.2 Informal conditions and implications

“Managers, who do not know how to measure what they want, settle for wanting what they can measure.”

Ackoff, Addison, & Bibb (2006, p.4)

Prior research discusses the impact of culture, collaboration and the organizational climate when implementing and using the LPS, where management and leadership commitment is important in order to achieve positive results and continuous improvement (Porwal et al., 2010). The process of implementing systems for measuring performance is challenged with both organizational and behavioral issues (de Waal, 2003), and our literature study indicates that there seems to be a gap in prior research concerning this important topic.

Over the past five to six decades, the role and incentives of performance measurement have become a highlighted topic of debate. Many researchers bring up this subject, for example, Locke (1968) who found a direct relationship between an individual's performance to accomplish a specific goal, and the difficulty of achieving that goal. He also found that the hard goals turned out to produce a higher level of performance than the easier goals did and that explicit goals gave better output than "do your best" goals. In 1990, Locke collaborated with Gary Latham in the field of goal setting and proposed a set of principles that should be considered when setting goals, these being; clarity, challenge, commitment, feedback, and task complexity. On the other hand, Ordóñez, Schweitzer, Galinsky and Bazerman (2009) discuss the systematic side effects of over-prescribing goal setting, where goal setting has predictable and powerful side effects which are far more serious than prior research has acknowledged. In their study, they conclude that the systematic harm caused by goal setting has consistently been ignored and that the damaging effect of goal setting outweighs the benefits. As a counterargument, Locke and Latham (2009) argue that there is a positive linear relationship between task performance and goal difficulty, assuming that the individuals are committed to the goal, do not have any conflicting goals and have the requisite ability to meet the goal. In fact, Latham and Locke (2006) identified several pitfalls and enabling factors.

In summary, they acknowledge that setting challenging, and specific goals might have potential drawbacks. However, they believe that these drawbacks can be prevented or overcome by applying the recommendations that they present in their research. The following points summarize some of these;

- *Let high-performing individuals set their own goals and strategies to meet these goals.*
- *Assign a reasonable number of goals and make sure that the difficulty of the goals is proportionate with the self-confidence of the employee.*
- *Leaders must be able and willing to reassess plans and goals based on the results they observe.*
- *Celebrate and encourage learning, especially learning from errors. This will help to keep the focus on tasks rather on individuals.*
- *Frame the goals in a positive way.*

Another aspect is how performance measurement influences an individual's self-confidence. Bandura (1982, 2010), known as the originator of social cognitive theory, defined self-efficacy as an individual belief in one's ability to accomplish a task or succeed in specific situations. In their study, Stajkovic and Luthans (1998) found that self-efficacy is strongly and positively linked to work-related performance. Individuals with high self-efficacy will perform better with a higher likelihood of successful outcomes, whereas individuals with low self-efficacy are more likely to fail (Bandura, 1982, 2010). Furthermore, Ozyilmaz, Erdogan & Karaeminogullari (2018) found in their research that self-efficacy had positive effects when the organizational trust was high and thereby led to increased task performance and job satisfaction.

Previous research has suggested that there are issues related to both data access and cultural and political aspects when it comes to implementation of performance measurements. Neely notes that negative data from the performance measurements can often be used in an intimidating and judgmental way by the management, which encourages a more defensive behavior amongst the employees. Due to people's fear of such negative measurements, the data might consequently end up being inaccurate, or even manipulated, in order to make sure the targets are seemingly being achieved so that there is no blame to be distributed (Powell, 2004). Bernstein (2012) highlighted the transparency paradox of performance measurement technologies, where workers engage in time-consuming behaviors to hide aspects of their work. Furthermore, he discusses whether observing employees indeed have a positive effect on productivity and performance or if monitoring and observing both constrain and demotivates employees and thus has a negatively impact. His empirical findings showed that even a modest increase in privacy on group-level significantly and sustainably improved performance and that privacy is an important factor to encourage continuous improvement and avoid distractions. A key takeaway from Bernstein's research is that transparency is, in general, a positive thing, also across hierarchical levels. However, if this transparency results in an experience of being programmed and controlled, with for example detailed behavioral recommendations written in manuals, it will inhibit productivity.

Fischer et al., 2017 argue that achieving optimal performance is feasible when one is able to manage and strengthen the project team, this includes amongst other things; training and mentoring, clear communication and understanding of values and goals. Furthermore, they state that the team dynamic can make or break a project and that the teams should have a way of communicating efficiently and reliably. Project teams always produce much information concerning, among other things; schedule, quality, turnover, and procurement. This information is necessary in order to attain high quality and safe production, but it is, however, questioned whether the right people are doing the right things at the right time. If this is not the case, then money and time will be wasted. Therefore, the research emphasizes that teams and disciplines should have a systematic and efficient way of communicating reliably and accurately. Moreover, this system must be well integrated in order to achieve better performance, where everyone should have access to the most recently updated information at any given time (Fischer et al., 2017).

3.5 Theoretical background summary

This section presents a wide range of insights from previous research to get a better understanding of performance measurements within the context of Lean Construction. Theories from several different research areas have been considered in order to cover all the underlying aspects of our study. The review of concepts and theories from each area, and implementing them into our empirical context, constitutes an academic basis for the discussion of our research questions. This was necessary due to the fact that there is little research that has the same focus as this thesis; explore and discuss the different aspects of how Lean Construction performance is being measured.

As previously mentioned, it is a widespread belief that the construction industry over the past decade has been facing a negative trend considering productivity and efficiency (Allmon et al., 2000; Barbosa et al., 2017a; Force & Britain, 1998; Miller et al., 2009; Øye, 2019). As a result, more attention is drawn towards figuring out how to counteract this trend and find ways to make productivity improvements (Aziz & Hafez, 2013; Bertelsen, 2003; Koskela, 2000). A number of theories have been implemented to improve performance; among these are the LPS (Langlo & Andersen, 2016; Macomber et al., 2005). However, Nadim and Goulding (2011) blame the industry's lack of attention towards adapting to and applying methods and tools for improvement for the negative trend in productivity.

From the literature study, several different perspectives have been discussed regarding the process of measuring performance in the construction industry, performance measurement set in the context of Lean Construction, and the challenges and implications of measuring performance. It is the combined consideration of these areas that creates the theoretical basis for our thesis. Prior research identifies the means and ways of measuring performance an important area, arguing that by developing and implementing a balanced set of measures, business performance can be enhanced (Kaplan & Norton, 1992; Neely et al., 1996). To influence behavior and to identify potential areas for improvement seems to be a common denominator to measure performance (Beatham, Anumba, Thorpe, & Hedges, 2004; Deming, 1968; Robinson, Anumba, Carrillo, & Al-Ghassani, 2005). It is further argued that performance measurement will provide a sense of where we are, and where we are heading, and will in that way create feedback on the effectiveness of improvement interventions (Cohen & Levinthal, 1990; Liebowitz, 2004; Rose, 1995). However, it is neither the act of measuring nor the resulting data which will generate results; it is only when they are exploited that they will accomplish satisfactory results (Behn, 2003).

The interplay and combined consideration of performance measurement and Lean Construction have, as mentioned, not been sufficiently understood and explored by prior research. However, we believe that our theoretical review sheds light on important aspects of performance measurement within the context of Lean Construction. A theoretical framework (Figure 6) based on the preceding review, was created to use in the empirical study and discussion of findings.

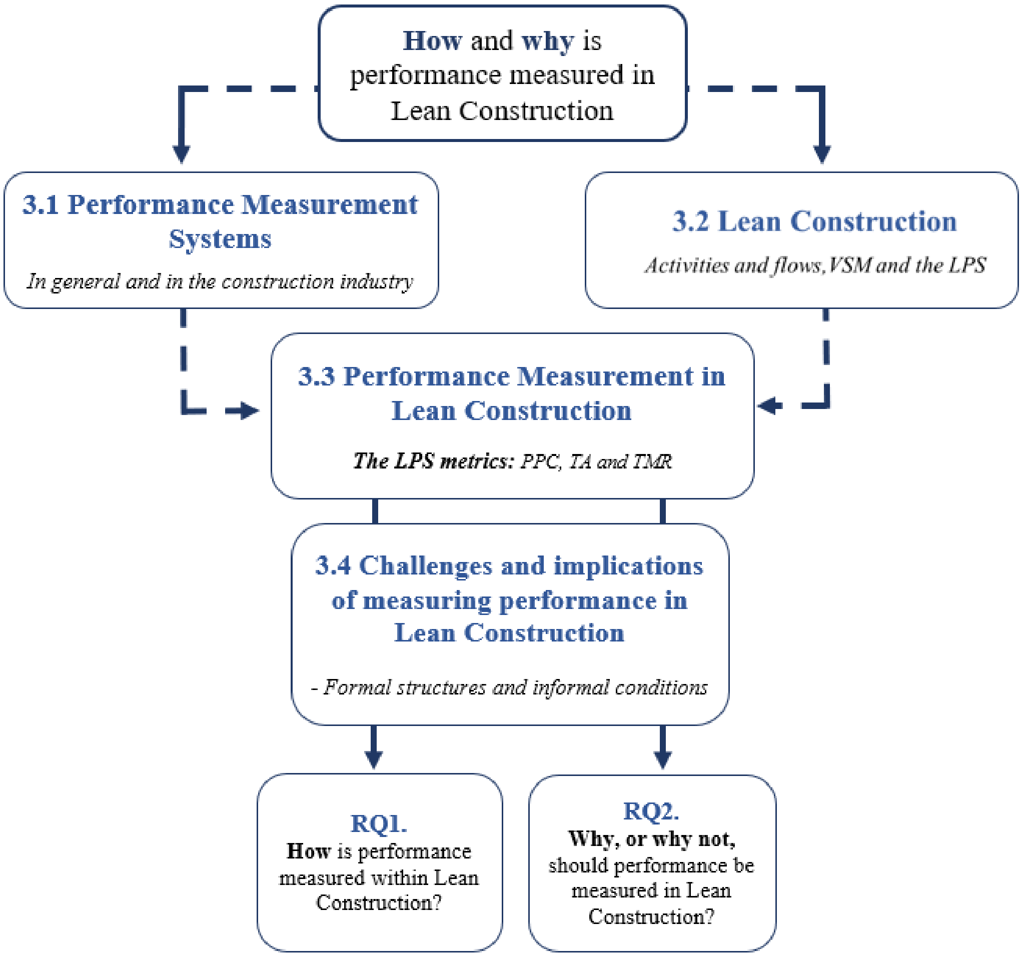


Figure 6: Theoretical framework

The theoretical framework illustrates several aspects that were found important to study in order to answer our research questions. The framework serves as a basis for our empirical findings and discussion whereas theories from different researchers have been combined to create a solid background for investigating the different aspects academia presents on performance measurement (3.1) and Lean Construction (3.2). Further, we focus our study on examining performance measurement in the context of Lean Construction (3.3) and address the formal structures used to measure performance in Lean Construction. Lastly, we deliberate on the impact of challenges and implications regarding formal structures and informal conditions in the implementation and use of performance measurement in Lean Construction (3.4). This provides the base for discussing our two aligned research questions, and evaluate whether, or not, performance measurement should be carried out in Lean Construction projects.

Modig and Åhlstrøm (2018) discuss the efficiency paradox, arguing that companies often allocate a significant amount of time and resources on non-value adding activities. They state that focus on flow efficiency could eliminate these activities, and thereby increase productivity. Perhaps, through performance measurements and VSM, several of these activities could be more visible (Chew, 1988; Rother & Shook, 2009). According to the study conducted by Liu, Ballard, and Ibbs (2011), productivity is anticipated to be significantly positively correlated with measuring PPC. However, as highlighted by several researchers (section 3.4) there are also challenges and implications related to the process of implementing and using systems and techniques, such as LPS, for measuring performance. Adjustments are required when implementing Lean in the construction industry; this is due to the complexity of the industry and the different projects (Saurin et al., 2013). In addition, an important remark made by Porwal et al. (2010) is that one of the challenges is due to only partial implementation of tools and techniques in the LPS. This is supported by Sage et al. (2012), who argue that Lean tools and concepts, such as LPS, should be implemented within the entire production process as a strategy.

The literature highlights the importance of having consistent formal structures when implementing the LPS and measuring performance. However, it is also emphasized that the informal conditions have to be considered (such as self-efficacy), both when implementing Lean Construction and measuring performance in Lean Construction (Bygballe et al., 2018; Green & May, 2005; Sage et al., 2012). Because, as mentioned earlier, there are both organizational and behavioral issues related to performance measurement. Some emerging from the way the measurements are used in retrospect (Powell, 2004), and others related to the potential drawbacks of setting ambiguous, or challenging, goals. The question of whether the effects of measurements and goal setting are always beneficial is a source of much debate. Leading thinkers within the field of goal-directed behavior (Locke & Latham, 2009) and critics of setting targets (Ordóñez et al., 2009) presents valid points discussing important aspects considering how goal setting in organizations should be implemented and performed (Neely et al., 1996). A substantial literature has demonstrated how goal setting improves task performance (Locke & Latham, 2009). However, research has also introduced a dark side of goal setting, linking unethical behavior to high-performance goals (Ordóñez et al., 2009). This concern was also shared by other researchers who argue that self-efficacy is strongly and positively related to work-related performance, however depending on task complexity (Stajkovic & Luthans, 1998). Additionally, Bandura (1982, 2010) argues that individuals with high self-efficacy will perform better with a higher likelihood of successful outcomes, whereas individuals with low self-efficacy are more likely to fail. In 2007, Womack et al., argued that performance measurement is not worthwhile, and time should instead be spent on improving performance and process by implementing Lean techniques. It could, therefore, be interesting to evaluate if performance measurements are according to Lean thinking, and in that sense, can be noted as a value-adding activity.

4. EMPIRICAL FINDINGS & ANALYSIS

The following chapter presents a combination of the empirical findings and analysis performed in our research. Our thesis aims to investigate and discuss the various aspects of how Lean Construction is measured, including both formal structures and informal conditions of performance measurements. We have performed an exploratory case study of Veidekke by collecting data from six of their construction projects, in order to provide an in-depth understanding of our research questions. The first section in this chapter presents the empirical setting and Veidekke's adaptation of Lean Construction. The second section introduces the empirical findings and analysis, which is based on the structure of the theoretical framework.

4.1 Introduction of case study

Veidekke is the largest construction company in Norwegian, and one of the leading in Scandinavia (Veidekke ASA, 2019). They have been working with Lean Construction since early 2000, and have had an important role in developing the Norwegian Lean Construction network (LC-NO). In 2002, Veidekke started to explore means to reduce sick days and increase productivity. Their work with Lean Construction started with implementing tools like the LPS, and a greater focus on collaboration was the starting point for a methodology they called "We at Veidekke". The goal was to change the culture and improve the work environment, reduce time loss, avoid dangerous events, and create flow in production. In order to achieve this, everyone had to be involved in the improvement work, where the involvement was mainly divided into two factors; social rules, and the projects common goals. The social rules were summarized in a written group agreement, while the project goals were summarized into a type of plan. The goals included in this plan were then divided into result goals and process goals, with result goals being the final results of the initiated work, while the process goals are related to the processes that will lead to the result goals. The result goals could be divided into result based, such as economic parameters, and progress based, which concerns delivering on time and reporting deviations (Aslesen & Bølviken, 2017). "We at Veidekke" was later developed into "Collaborative Planning in Design and Production Management", for progress and production planning based on the principles of Lean Construction. Collaboration is the keyword for their methodology, as it aims to engage all the involved parties in the phase of developing the project plan, and can, therefore, be viewed as Veidekke's adaptation of the LPS. This also includes subcontractors who make up a large proportion of the employees in their construction projects and stands for half of their operational costs (Veidekke ASA, 2019a, p. 32). Some of the main elements of the LPS that have been included in their methodology is that; everyone has the needed knowledge and ability to influence their own work, the plans are made jointly by those who are going to do the work, the plans are made based on mutual promises and commitments, and the activities should be increasingly detailed as the execution approaches, where barriers are removed such that only the "healthy" activities (meaning activities that can be efficiently and correctly executed) are assigned to the workers.

This makes Veidekke an interesting case object for our research, both from a practical and theoretical perspective. Moreover, we will in this thesis focus on Collaborative Planning in Production Management, as we will mainly investigate the phenomena in production management and not in design management. However, we do believe that our findings could be applicable for Collaborative Planning in Design Management as well. The timeline of CP, how it has developed over the years at Veidekke, is illustrated in the following figure:

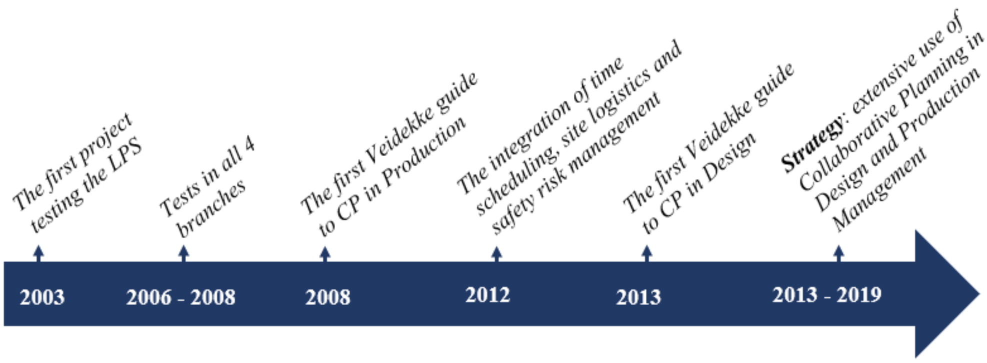


Figure 7: Timeline - Collaborative Planning in Veidekke

Previous studies into Veidekke's construction projects have shown that approximately 60% of time spent can be defined as productive time and the remaining 40% as lost time (Veidekke ASA, 2019b). These categories can be further broken down into execution and planning (direct and indirect labor), and unproductive and counterproductive time. Veidekke´s experience is that one can reap even greater productivity improvements by continuously reducing the proportion of the lost time.

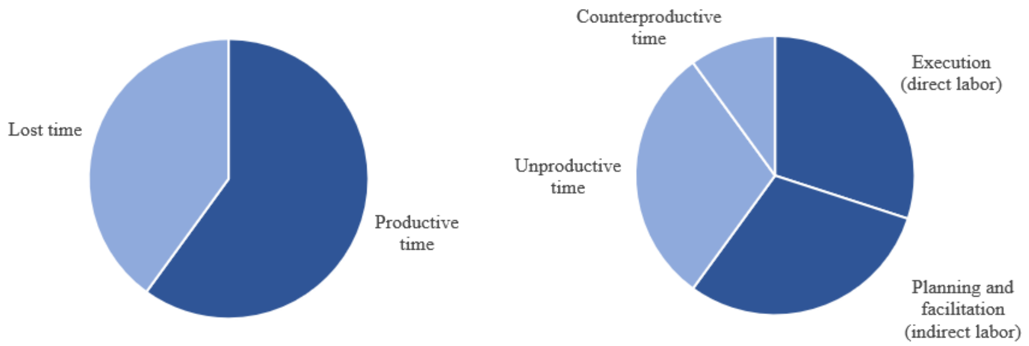


Figure 8: Study on workflow and lost time in production (Veidekke ASA, 2019)

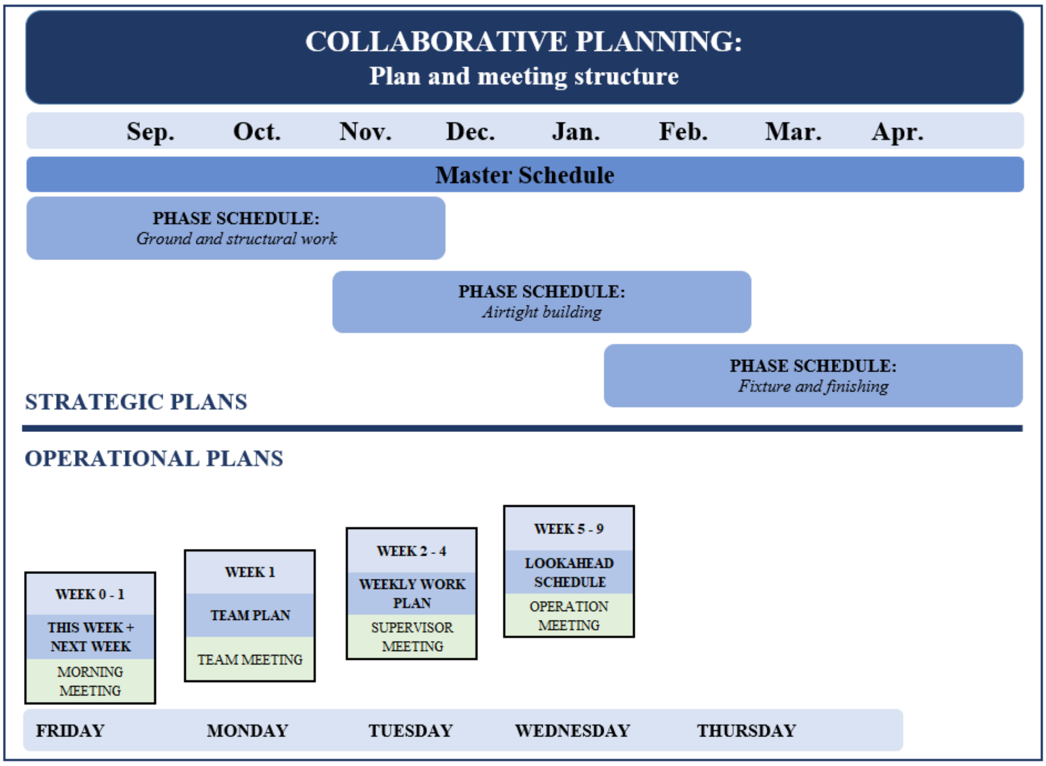
In order to improve these numbers, they have focused on five main aspects of their methodology:

1 *Focus on both long- and short-term planning.*
2 *Develop a systematic method to remove and mitigate production barriers.*
3 *Each strategic plan should contain more detailed and operational plans.*
4 *The meeting structure should match the plan structure.*
5 *A systematic risk analysis should be done continuously.*

All new employees at Veidekke are invited to participate in an introduction course to Collaborative Planning (CP), which is a part of several modules toward learning more about the methodology. The course material is based on two guidelines which Veidekke has developed to cover important aspects of CP. These guidelines are meant to serve as an encyclopedia, one for CP in production management (CPM) and one for CP in design management (CDM). In the guideline for CDM, the performance measurement metric PPC is presented as an important metric that addresses whether they are able to fulfill their commitments or not. On the other hand, the guideline for CPM emphasizes the planning and meeting structure, where performance measurement metrics are not addressed.

The purpose of the meeting structure emphasized in CPM is to follow up the various strategic and operational plans. In the strategic plans we find the master schedule and phase schedules, which are usually only prepared once in the project. In LPS, there are two operational plan levels; the lookahead plan and the weekly-work plan. Moreover, all operational plans in CP are rotating and should be updated every week. There are different participants at the different meetings, for instance, in the phase-schedule meetings the construction manager, superintendents and foremen are present, in addition to the project manager and foremen from the subcontractors.

The following figure illustrates the plan and meeting structure in CP, including plan levels, those who are responsible for the meeting and the time schedule.



	Plan levels	Responsible	Time Scheduling
	Project development and design	**Project manager and Design manager**	**Pre-project / Initiation stage**
1	Master Schedule	Project manager	Before start-up of project
2	Phase Schedule (for each phase)	Site manager	Phase schedule meeting
3	Lookahead schedule (5-6 weeks)	Site manager	Operation meeting
4	Weekly work plan (2-4 weeks)	Foreman	Supervisor meeting
5	Team plan (upcoming week)	Team supervisor	Team meeting
6	Last check-out	Individually, and team based	Morning meeting
	Running operations	**Each and everyone**	**In their work**

Figure 9: CP - Plan and meeting structure

The elements in Veidekke's five main aspects resemble Ballard's (2008) four critical characteristics to assess the final quality of the activity:

1. *The activity is well defined to a sufficient degree so that the understanding of it is unambiguous when the activity is completed.*
2. *There is a correct work sequence that is compatible with the internal logic of the work task, overall project obligations and goals, as well as the chosen implementation strategy.*
3. *The proper amount of workload has been selected for the duration of the plan.*
4. *The work activity chosen is feasible.*

Veidekke has further defined seven conditions to assess whether an activity is "healthy", or not (Aslesen & Bølviken, 2017, p. 126). A healthy activity should be possible to efficiently execute without any obstacles, with correct quality and according to health and safety requirements. These activities are dependent upon the following;

- *External conditions*, which are uncontrollable variables like for example, regulatory approvals and weather conditions.
- *Connecting activities* that must be completed according to the plan and that meets the quality requirements, so that work will not need to be redone.
- *Information* flow of necessary and correct information, for example, approvals and decisions must be available at all times.
- *Components, materials* and *equipment* of correct quality and quantity must be available when needed.
- *Workers* must possess both competence and capacity.
- The workspace (referred to as *space* in the figure below) needs to be tidy and security measures must be in place.

These conditions are an interpretation of what one should do to avoid the seven types of waste that were presented by Koskela (2000). This obstacle analysis could resemble TA and TMR, as previously discussed in 3.5.1.1.

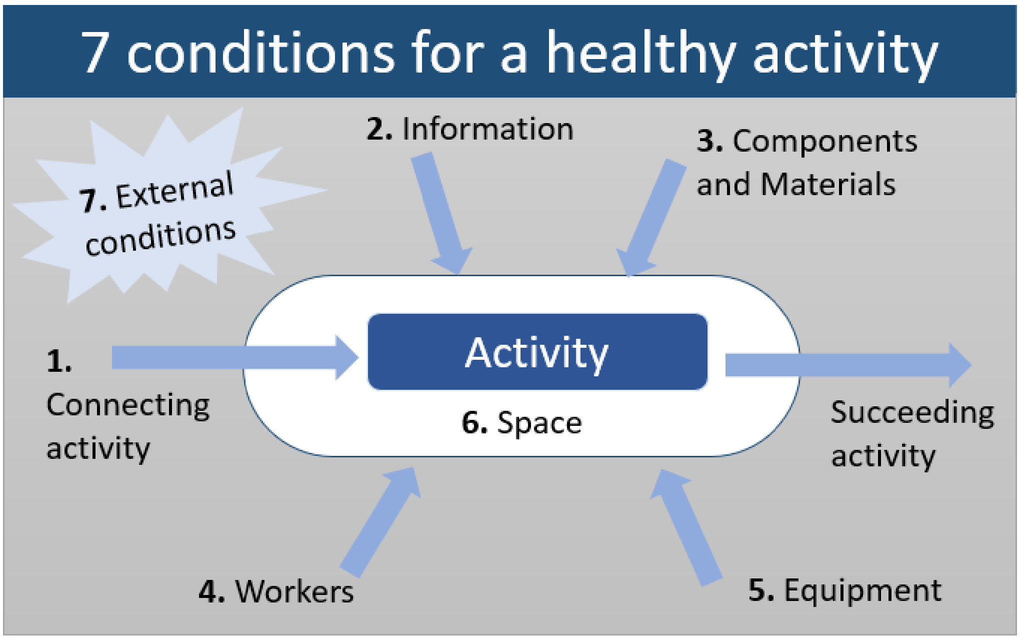


Figure 10: Seven conditions for a healthy activity

Veidekke believes that the supervisors and workers will be more committed to the project if they can decide and select which of the activities should be included in the lookahead plan (Aslesen & Bølviken, 2017). This should also result in more accurate plans, as the workers typically will have a better knowledge of their profession and time required for each activity.

The following section presents our empirical findings and analysis of the case study which is based on the six residential projects: Frysjaparken, Nyegaardskvartalet, Ulvenparken, Hagebyen, Sølvparken, and Gartnerkvartalet. Veidekke is the main contractor in all of these projects, but still, they all had different strategies with respect to time and quality. Furthermore, they were in different project phases, where some had just started and some had already ended (see Appendix 4 and Figure 3). We interviewed several key participants from all of these projects to get a holistic overview of the topics relevant to our research.

4.2 Empirical findings and analysis of the case study

In this section, we combine our empirical findings and case study analysis. We start with the motivation and drivers for measuring performance in Lean Construction, and will address the attitudes towards, and prior knowledge of performance measurements. In the following subsection, we discuss how, and if, performance measurement is implemented and used in the project, and how it is used for further learning and improvements. Lastly, we will reflect upon the informal conditions and implications that our interviewees shared with us, such as barriers toward being measured.

4.2.1 Motivation and drivers for measuring performance in CPM

Our second research question aims to reveal whether or not companies should measure performance in Lean Construction, and whether performance measurements are value-adding activities that construction companies should employ in order to increase their productivity. Accordingly, this subsection presents our findings regarding the motivation and drivers for measuring performance. Here we also discuss the different views regarding productivity in the construction industry and the role of performance measurement in CPM. Further, we will address our findings concerning whether performance measurements are deemed as a value-adding activity amongst our interviewees, or not. The empirical analysis was structured in the same way.

4.2.1.1 Views regarding productivity in the construction industry

There are several views of the productivity in the construction industry, and how, or even if, this can be improved. The interplay between the increased interest in performance measurement and the challenges related to productivity is as mentioned the starting point for our research. It was, therefore, natural to reveal the different views and opinions amongst our interviewees regarding the productivity in the construction industry. This was useful as a basis for discussing whether, or not, performance measurement could be used to reverse the alleged stagnated trend in productivity.

> *"The construction industry is lagging behind." Interviewee # 8*
>
> *"My opinion is that it has been very primitive, highly influenced by coincidence. With an absence of structure and systematics in the way you work." Interviewee # 1*

It was a clear consensus amongst the interviewees perceiving the productivity as stagnating in the construction industry, and a common argument was that "we still have a lot to learn". It was said that the construction industry often is compared to the industrialization that takes place in other industries. Several of the interviewees, however, stated that the recurring argument amongst field experts and researchers tend to not take into account the impact of different innovations and changes that are happening in the construction industry, thus affecting the productivity in the construction industry in more areas than what is captured by the statistics (e.g. SSB).

> *"I hear and read that many believe that the productivity in the construction industry has declined. Then I myself ask if they really know what they are talking about." Interviewee # 3*
>
> *"Those who speak out, either they do not understand what is happening on a construction site and say whatever others have said, or they overlook and do not really think it over." Interviewee # 13*

When discussing this concern with the professor from NTNU, it came clear that numbers on productivity from SSB is not considered reliable. This is because this type of analysis demands a greater deal of processing and combination of sub-quantities data for them to be representative at all. He also highlighted the fact that the construction industry's extensive use of foreign workforce and agencies for staffing can have unintended effects on the statistics.

4.2.1.2 The role of performance measurement in CPM

According to Veidekkes the CP guidelines and Aslesen and Bølviken (2017), the intention with CP is to motivate and give each discipline, and subcontractor, greater ownership during the project execution process. The majority of the interviewees regard CPM as an important methodology to create better flow and efficiency in the projects. They recognize and take great pride in the work concerning CPM, especially with the meeting structure and mapping the different conditions for each activity throughout the project phase. However, some interviewees do not define their project as a CPM based project, although they incorporate several aspects from it. Most of the interviewees that claim they follow the CPM methodology, however, seem to lack knowledge related to some aspects of it, especially metrics used to calculate performance measurement. Some stated that with a thoroughly structured and prepared lookahead plan enables to do such measurements in the weekly work plan much more effortless.

> *"The Lookahead plan has the best starting point if it includes input from everyone involved in the project."* Interviewee # 10
>
> *"We believe that the best and quickest way to solve things is by involving subcontractors, craftsmen and suppliers."* Interviewee # 4

Our findings show that there is a widespread belief that personal commitment to the lookahead plan will motivate those involved to deliver according to the given specifications. Through CPM, project managers are able to get direct input from the different disciplines when planning and determining each activity in the lookahead plan.

> *"We sometimes say that 'based on previous experience, it should not take this long time'. It is just as foolish to set up too much time as the opposite."* Interviewee # 10

However, some of the interviewees have pointed out that the different disciplines or subcontractors demand far more time to execute an activity than what seems to be necessary. Whereas one of the project managers revealed that, they reduced the initial time set by one of the subcontractors with more than 50%, even with strong disagreements from the subcontractor. However, when later reviewing the recording of the performance, it turned out that the subcontractor had further reduced the duration from the initial week to only a couple of days. Some interviewees stated that another reason to include the subcontractors in the early planning phase is that they could use the agreements as leverage if the subcontractor does not deliver according to the weekly work plan.

> *"We would then have a better basis for price-negotiations with the subcontractors." Interviewee # 8*

4.2.1.3 Is performance measurement deemed a value-adding activity

Performance measurements are a time-consuming process, or at least it seems to be a common belief among several of the interviewees. A typical argument is that there are so many things that should be prioritized before spending time on measurements, and for those who use measurements it can sometimes be challenging to prioritize time to do it as well.

> *"I have to admit, that it is sometimes difficult to prioritize the time." Interviewee # 6*

On the other hand, the majority of the interviewees regards the performance measurements as an essential prerequisite for obtaining a good lookahead and weekly work plan and considers it necessary in order to be able to prioritize their time right. Their experience is that performance measurement enables them to spend time on what is needed, instead of spending unnecessary time on disciplines that do not need follow-up, for instance.

> *"But the measurements, or the hour set aside for lookahead planning and the meeting where you compute the measurements, can form very important courses for how we develop and change the plan further." Interviewee # 9*

One of the participants also explained that the process was not that time consuming for him, arguing: "When you first work on the plan, you just register why you have not reached the plan." Interviewee # 3. Some of the interviewees also argued that it is through performing measurements they gain time, and therefore, they believe that they do not have the time to "not do" measurements.

"No, we do not spend much time on it. I have the impression that many are afraid that it demands a lot of work in the lookahead plan. But as soon as you make measurements on it, it requires you to have a good plan." Interviewee # 10

Before analyzing what is measured within Lean Construction, there are some prerequisites found important to evaluate considering the value of measuring performance. As discussed in subsection 3.3.2, an important aspect of Lean is the process of identifying waste and non-value adding activities. The value added by an activity should be positive, meaning that it should be equal to or greater than the cost incurred. This thesis does not calculate the cost of measuring performance. However, time in the construction industry is a costly resource. The process of measuring performance could, as mentioned, potentially be time-consuming and thus has to provide more added value than it would if time was prioritized differently.

"Why should you spend time measuring something that has already been done? If something has gone wrong for a discipline, how could you use that information when the activity does not repeat itself later in the project." Interviewee # 9

Several of the interviewees raised concern regarding how they can systemize performance measurement in a way that it provides the value necessary to defend the time spent, which is grounded in the mindset behind Lean. They argue that time should be prioritized differently if one does not understand the purpose of performance measurements. In addition, one of the interviewees stated that he did not see the value of measuring performance since they did not have any particular challenges related to productivity in residential production. However, other interviewees argue that it is through measurements they are

"Measurements provide a quick and reliable overview, and a straightforward understanding of the situation. That is the most important effect of it." Interviewee # 1

able to reduce time spent on non-value adding activities. They believe that performance measurement allows them to focus on continuous improvement, and potentially provide them an indicator of how good, or poor, they are performing. It was also stated that the measurements allowed them to bring the learning and experience with them into future projects to a greater extent.

One of the project managers also argued that "the value of having it written is quite substantial because then it becomes more visible and transparent." Interviewee #8. This was also supported by the professor from NTNU, who further argued that the most important aspect of performance measurement in the construction industry is to provide the possibility of measuring the effect of different improvement measures on both process and project level. A notable observation, both during interviews and participation, was the importance of structured systems and methods for performance measurement. It was stated several times that an important prerequisite for measuring performance is that there are reasonable and feasible methods and tools for this purpose. Some of the interviewees admitted that even though they did perform some sort of performance measurements, they were not good at documenting it. The systems allowed for several types and methods for documentation, and the participants did register the different reasons for deviation, i.e., the underlying factors for the deviation to occur. However, this learning and evaluation were not taken further into new projects or for continuous improvement in the organization.

> *"Measurements show where the potential for improvement lies, if you never measure then you cannot point to anything." Interviewee # 6*

It was recognized that several of the interviewees found performance measurements, and the metrics within the LPS, quite comprehensive and complex, and therefore questioned the value of it. Participants throughout the organization shared these reflections, and some of them

> *"Even I thought it was burdensome on the first project, and I did not quite understand the priority or was really good at prioritizing it at the beginning either. However, the more you use it, the more you understand and see the value of it. And at the end, you realize that you do not have time to not measure." Interviewee # 6*

concluded that it might not be useful for them to implement much because of the "hassle" of doing it. However, one of the project managers admitted that he was one of those who questioned the purpose and necessity at the beginning, but after using it for a certain time, he began to realize the value of it.

One of our main empirical findings was that a unified understanding of the project plans is vital in order to achieve improvements, which is also considered as one of the main elements in CPM. In our quantitative research, we analyzed "hit on schedule" by looking into the number of planned activities compared to the number of activities completed, as seen in Figure 11 and Figure 12. First, we see that the number of planned activities changes rapidly from week to week, such as week 5 to 7 at Frysjaparken. A construction manager mentioned in one of the meetings that this could indicate that the lookahead plan did not emphasize efficient planning in order to avoid a poor workflow. Secondly, by looking at the trend at both of the projects, an increase in the number of planned activities seems to affect the PPC negatively. Lastly, our calculations show that there is approximately 84% hit on the plan on average for Hagebyen and 79% for Frysjaparken (refer to Figure 13 and Figure 14).

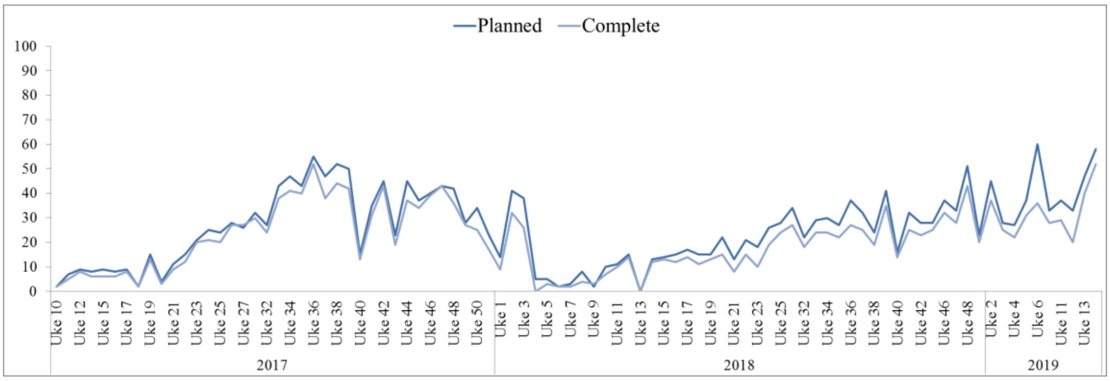


Figure 11: Planned versus completed – Frysjaparken

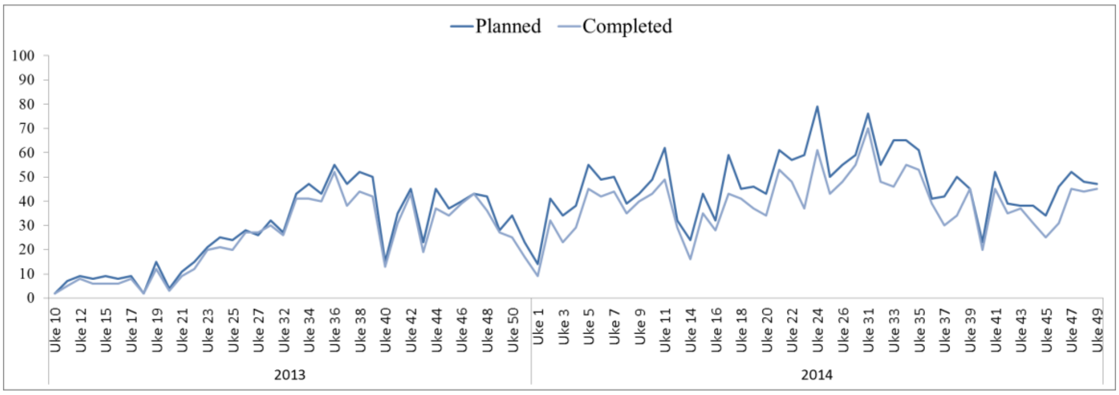


Figure 12: Planned versus completed – Hagebyen

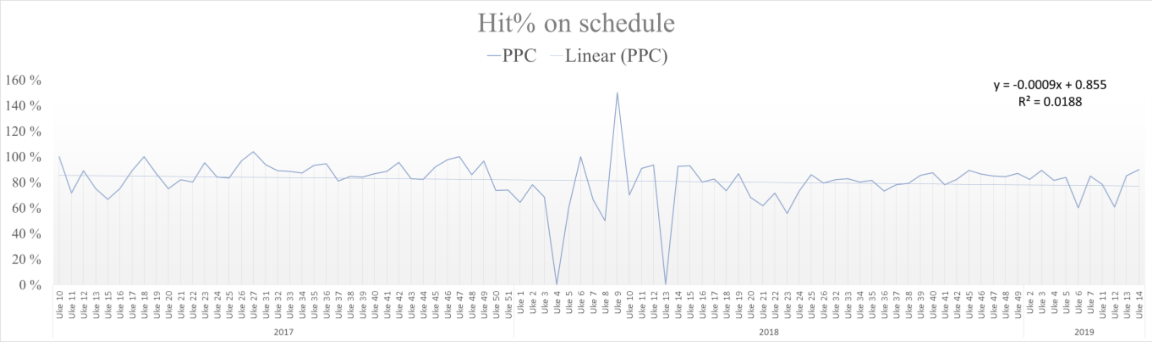


Figure 13: Hits on schedule – Frysjaparken

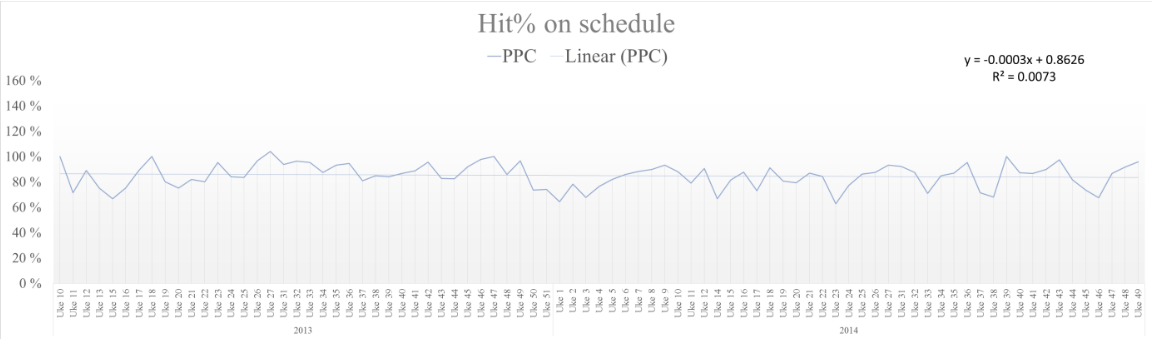


Figure 14: Hits on schedule – Hagebyen

4.2.2 How is performance measured in Veidekke's CPM?

In order to investigate what is measured within Lean Construction, we have focused on the different formal systems and tools that are used to measure performance at Veidekke. During our data collection, we gained insight into the role of CPM and how they link this methodology with performance measurement. In this subsection, we present which metrics Veidekke uses for measuring performance, those who are, or is considered, responsible for executing the calculations, and how it is adapted and analyzed in the different projects. This subsection will also address some of the barriers and implications related to the formal structures of measuring performance in Lean Construction.

4.2.2.1 Performance metrics used in Veidekke

Several interviewees and our observations confirm that a well-developed lookahead plan, coherent with the project plan, is important throughout the project execution process. According to the interviewees and our observations, there is no commonly acknowledged or shared methodology

> *"PPC measurements gives us a better indication and overview, it provides us the value of having it written down." Interviewee # 10*

of measuring performance based on the activities in the weekly work plan. Some state that they do not use the metrics from LPS to measure performance, however, later correcting themselves by clarifying, e.g., "We kind of measure productivity on the construction site. We have done it without calling it PPC, TA, TMR. We do it by looking into the project status". Interviewee # 3. "We probably measure more than we can show and point to. There are actually many measurements behind this plan." Interviewee # 4. Our additional questions revealed that productivity was not measured systematically by several of the projects. An overall impression was that neither of them was consistently measuring every discipline's on-going activities for a given timeslot, nor did they devote time to document the calculations or reasons for deviation. Consequently, the same mistake occurred several times in many projects, because it was not registered anywhere. An example of this was when one of the architects on the project was replaced, and the new architect was unaware of the changes that had been carried out earlier in the project. As a result, the mistakes that previously had been rectified started to reappear.

"The reason to why we are not able to finish the activities is that the seven conditions for a healthy activity are not present. We need to measure the execution of the activities based on these seven conditions" Interviewee # 2

Our research reveals that activities that are performed but not included in the weekly work plan are not captured by any of the mentioned metrics, nor registered by any of the disciplines. Thus, the basis for the measurement of their productivity is solely based on the execution of the activities in the weekly work plan. This is illustrated through one of the interviewees´ statements, which emphasized that although there are many examples where the measurements might show that they are unproductive, however, it does not take into account the unplanned activities. It is, however, important to mention that although the activity is not planned for, it does not necessarily mean that it is a non-value adding activity. Some of these can derive from unmeasurable factors, e.g., necessary rework due to construction errors or design errors in the plan.

"PPC is something we have previously used in operational meetings for those disciplines who are lagging behind. It is a good way to give them a 'kick', and say, 'you need to start producing something'" Interviewee # 7

Out of all the on-going projects, only one of the projects used a specific metric to measure productivity, this was the PPC metric. In addition, they recorded why they were not able to finish a planned activity based to the seven conditions. The majority of the interviewees say that they focus on the seven conditions for a healthy activity to ensure flow efficiency at the construction site. However, our findings reveal different understandings on how to define the deviations. An example of this was when one of the projects were facing a discussion concerning which deviation to condemn when the discipline accountable for the main concrete struggled to finish their job due to bad weather conditions. Some stated that this was due to *external conditions*, which were possible to control, resulting in a PPC of 34.5% this week. A counter argument was that those who were responsible for the job should have anticipated this and uses a specific fabric to cover the area, which can be used to lift the snow away, thus minimize the time used to remove snow and clear out the workspace. They, therefore, argue that this deviation would be interpreted as fail in prior activities. In the following subsections, we present our analysis of PPC measurements and reasons for deviations from the two projects, Frysjaparken and Hagebyen.

> *"Everything is about preparing for the different activities. The metrics measure how good one is to analyze obstacles and how good one is to remove those obstacles. It is very important, and you can do this by following the meeting structure and dig into the data in order to find the right information." Interviewee # 2*

Reasons for deviations

When analyzing the PPC data conducted by project and construction managers from Veidekke, we see that regarding the trend in "reasons for deviation", the more frequently the PPC is registered, the easier and better it is to analyze and interpret the output. There are some weeks that the information regarding total, planned, and done activities are not registered, resulting in somewhat misleading information. Because of this, we chose to exclude the weeks that did not include information about either total, planned, or done activities were deleted from the spreadsheet. However, the overview we get based on the registered data is quite comprehensive and thus provides us with altogether thorough information. We see that the most common reason for deviation at Frysjaparken is *connecting activity (25%)* and *information (24%)*, followed by *workers (23%)*, *external conditions (10%)*, *equipment (9%)*, *space (6%)* and *components and material (3%).*

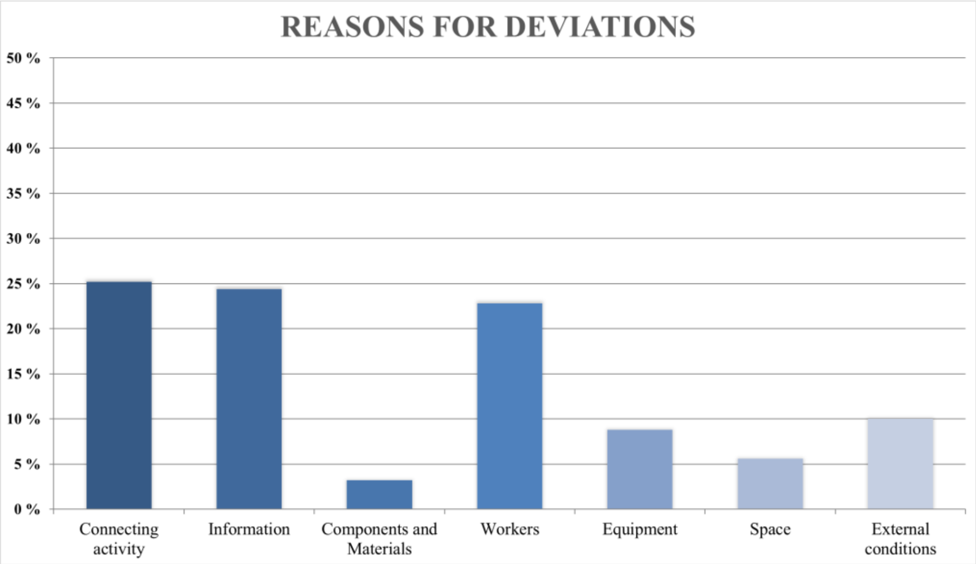


Figure 15: Reasons for deviation at Frysjaparken

We made the same assumptions when analyzing the data from Hagebyen as we did for Frysjaparken. Since some weeks did not contain any numbers of total, planned or done activities, these weeks were therefore omitted from the analysis. The data from Hagebyen is based on an interval analysis that lasts over two years, and we see that the most frequent reason for deviation here is *information (46%)* and *worker (24%)* followed by *connecting activity task (17%)*, *components and materials (8%)*, *external conditions (3%)*, *equipment(1%)* and *space (1%).* In addition to measuring PPC, Hagebyen calculates the cost impact associated with the different reasons for deviation.

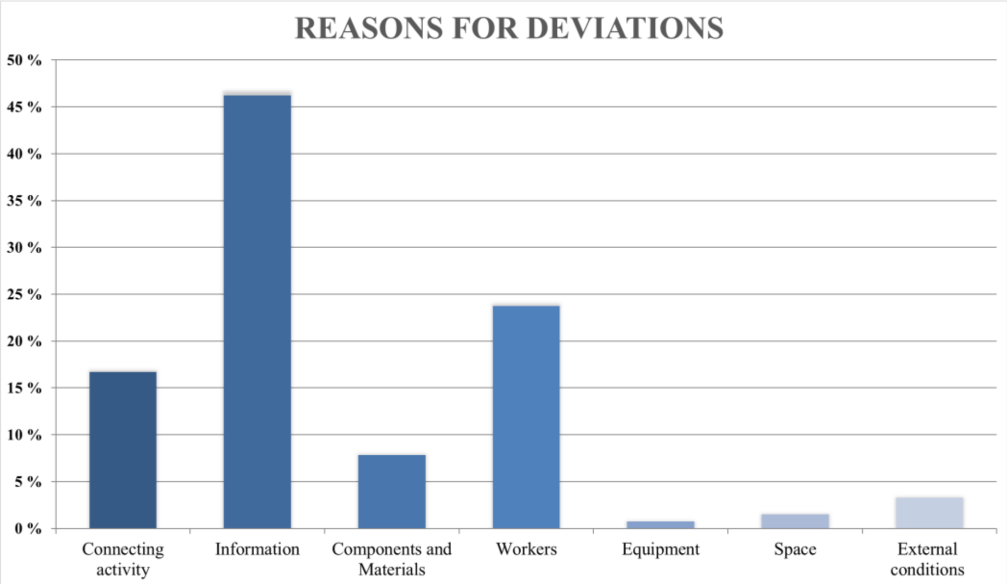


Figure 16: Reasons for deviations at Hagebyen

By critically scrutinizing the data and measurements from both projects, we were able to identify the actual source of deviation. Moreover, according to our root-cause analysis, the most repeating comments on reasons for deviation is due to the lack of anticipated tasks (TA) and task made ready for execution (TMR). This is illustrated by comments like: “Did not understand the task”, therefore, the PPC was just 33% in week 50 (2013) at Hagebyen, another example was “One day delayed because they had to clean the area before they could start their work”, week 7 (2019) at Frysjaparken, therefore, the PPC was 83% for this discipline.

This was also a note from our summary after the morning meeting at Frysjaparken 22.03.2019:

“*It seems like there is a lot of additional work done lately, this is because that the different disciplines do not clean up after they have finished their work.*”

Another, yet, relevant comment from the same morning meeting was that:

“The plumbers failed on which height the pipes were supposed to be, however, they later saw that it was something wrong with the project model.”

This was also the case a week earlier, at the morning meeting at Frysjaparken 15.02.2019; they argued that since the project model was not coherent with the drawings, additional work was required in order to follow the lookahead plan:

“We had problems with a prefabricated wall today, and the workers have to do some extra work to make it fit.”

Trends in reasons for deviations

When looking at the trend in reasons for deviation for Frysjaparken, we see that *connecting activity* occurs quite often, with a generally even distribution throughout the project's execution. We also see that at the end of the year 2018 and especially at the beginning of the year 2019, there seems to be a significant increase in the frequency of deviations. Our analysis of secondary data shows that in week three they had 0% on PPC due to lack of allowance to start the production, whereas in week six there was bad weather conditions and illness in the workforce that impacted the low PPC.

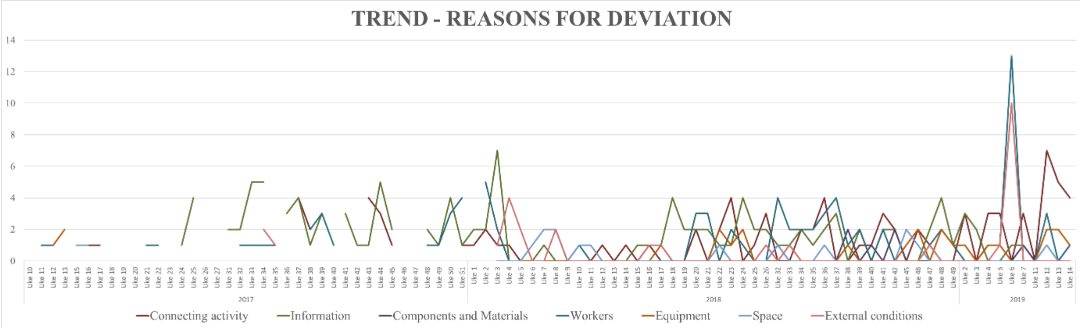


Figure 17: Trend in reasons for deviation at Frysjaparken (Appendix 5)

Considering the trend in reasons for deviation for Hagebyen, seen in the context of the frequency to the different reasons, information appears to be a relatively significant issue throughout the project. However, we also see that the category *workers* is quite significant, and especially challenging from the beginning of year two up to week 38. A comment noted in our secondary data showed that the main reason for deviation in week 23 was due to lack of information and follow-ups by the project manager.

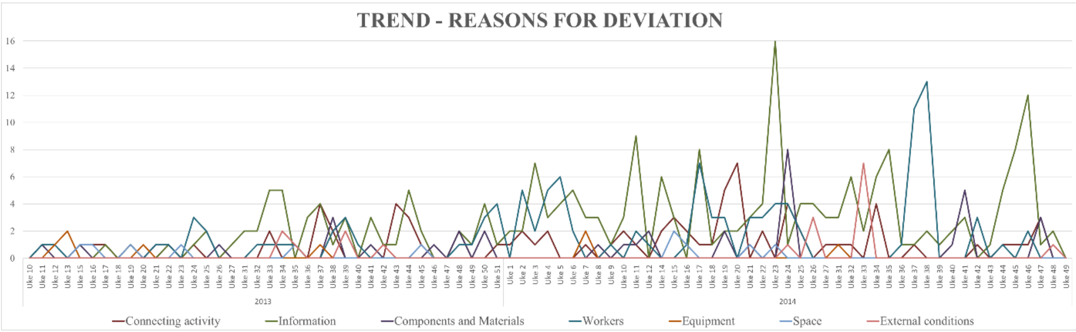


Figure 18: Trend in reasons for deviation at Hagebyen (Appendix 5)

Labor intensity

Labor intensity is a metric calculated by the project managers in both Frysjaparken and Hagebyen every week. This metric is measured by dividing the number of planned activities on the number of construction workers. Veidekke believes that they are to obtain a better workflow when the percentage is equal to 80 %.

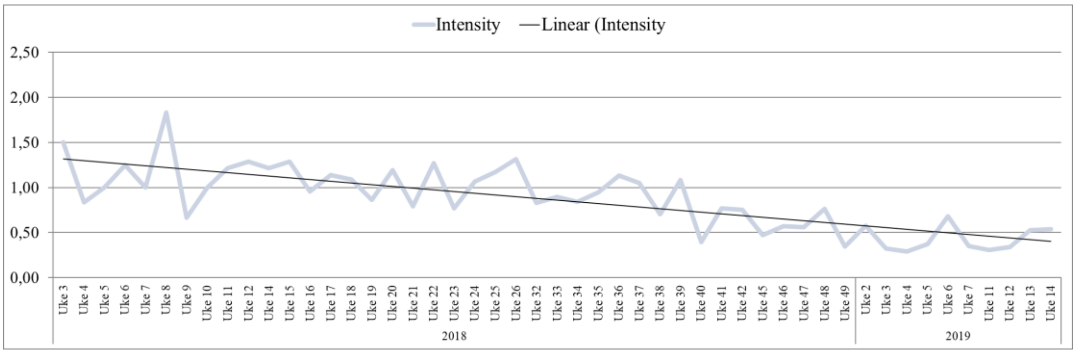


Figure 19: Labor intensity Frysjaparken

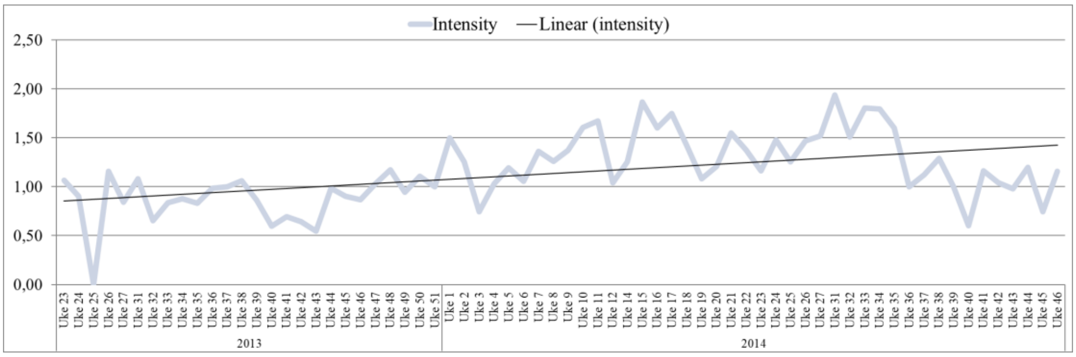


Figure 20: Labor intensity Hagebyen

Based on the linear analysis from both of the projects, we see opposing trends, where none of them fulfills their set goal throughout the entire project. The analysis shows that Hagebyen had satisfying labor intensity between week 33 to 36, and Frysjaparken also performed at approximately 80% between week 32 to 34. There seems to be a negative trend in the labor intensity for Frysjaparken, where the percentage has gone from approximately 135% to 40%. Whereas, in Hagebyen it starts at approximately 90% increasing to 140% at the end of the project. This could perhaps reflect an uneven distribution in planned activities and workforce.

4.2.2.2 Implementation and evaluation of performance measurements in CPM

Consistency and a well-implemented system are mentioned as two of the foremost important aspects in order to sustain good indicators. Consistency in the way that performance is measured plays a vital role, or else "the indicators will lose their value." Interviewee # 1. A well-implemented and structured system enables the users to get a better overview of the lookahead plan and to map the different conditions for a healthy activity.

> *"You can not only use the raw data only; you have to perform an analysis." Interviewee # 10*
>
> *"It is quite complicated, but it depends on how the job is facilitated by the construction coordinators." Interviewee # 11*

Those who have, to some extent, implemented performance measurement in their project have identified many possibilities, one of them being a motivational factor in reducing time and creating better workflow. In one of the projects, the project manager was able to reduce the time spent on each apartment by 50%, without creating any intrigues in the project.

In appendix 3, we see that the methods of measuring differ between the projects. Today, there is no given format by Veidekke. However, the majority of our interviewees wish for a shared method of measuring, which should be carried out systematically in the projects. Many of those who had no previous experience with performance measurement confessed that this had created insecurities and confusion. Our findings revealed that there had been performed measurements where one of the participants, recorded a team within one of the disciplines daily in order to map the time spent on each activity. One of the interviewees expressed his concern regarding this process, arguing that he did not understand how it could be beneficial to measure and analyze every different aspect of the workers daily routine.

"It could be really useful if one were able to secretly use and remove slack and waste on all the different disciplines and phases." Interviewee # 5

When visiting the other construction company, during an LC-NO seminar concerning performance measurements, we got insight into their method of measuring performance. This was done on through the "Touch plan", a digital construction planning tool designed for the LPS, where everyone had access and could see how the project progress was. This digital tool included lookahead and weekly work plans for the different disciplines, and different measurement metrics such as PPC. It was stated during our interview that the Touch plan enabled them to do this type of measurements systematically and meticulously. Accordingly, performance measurements procedures, as a part of Lean Construction, seemed to be well-established in their daily routines.

4.2.2.3 Who is responsible for measuring performance?

In order to grasp the different aspects of performance measurement, we wanted to gain a better understanding of who should be responsible for performing and controlling the measurements. Quite a few interviewees agreed that this responsibility should be handed to the middle-level managers such as the project manager, construction manager, or construction foreman. The latter depends on "if he can use

"My opinion is that it should be measured by the representatives of the different disciplines" Interviewee # 2

digital tools and systems; some individuals are analog. However, it is not being said that they perform poorly. It depends on the type of individuals you have in your team." Interviewee # 8.

Moreover, some of the interviewees utter a negative attitude towards being measured but would however like to measure those they supervise in order to gain better insight into how they are performing. Our research revealed that some of the representatives of the different disciplines do not always get as involved in the evaluation as they would like to. The empirical findings indicate that by including the disciplines in a greater extent would increase their motivation for productivity improvements. In one of our meetings at Sølvparken, it came clear that many of the project team members are young at age, and it was, therefore, more up to the project manager to decide on how things were supposed to be.

4.2.2.4 The process of learning and exchange of experience

In this subsection, we present how the interviewees adapt and make use of the performance measurements. There was some skepticism to why one should measure what has already happened and the fact that the same activity would not be repeated later in the project. However, there were other opposing viewpoints. One of the main arguments for measuring is that the findings and analysis can be a starting point for improvement initiatives for the following projects. It will be a way of exchanging experience and knowledge between the projects. Several of the interviewees utter a desire for a shared experience-database within Veidekke.

> *"It is like an experience-based database as well, where we can bring it with us into the next phase or project." Interviewee # 10*
>
> *"If it is not documented, how could you share experiences and knowledge in a reasonable and proper way."? Interviewee # 2*

One of the project managers admitted that a common issue he was facing was that construction workers were missing feedback on their progress and a more general basis. However, it is crucial to be aware of the way the managers present the feedback and how the construction workers understand it. Frysjaparken has monthly feedback meetings where the project managers do not present the actual PPC measurements, rather a general indication of how the project is performing.

Our research shows that there is a prevalent belief that by measuring performance, the managers are able to gain more time through better time allocation. As previously mentioned, some state that they use performance metrics to get an indicator of which discipline is struggling, and thereby focus their time to follow up these disciplines. Thus, those who perform well according to the metrics will not be followed up as closely as those who might need extra supervision.

"I used the PPC to prioritize which disciplines that needed to be followed up." Interviewee # 1

Based on both interviews and observations, our findings revealed that those who have measured performance and noted reasons for deviation gained a better overview of the challenges and the deviations throughout the project. The most persuasive argument for documenting the deviations was how the results could be used to improve the project flow. An example of this is how the project managers used the analysis to document that one of the construction coordinators on several occasions forgot to order on time and provide feedback in order to change the behavior.

"Everyone had learned and worked their way throughout the process. It helped to have more or less the same activities and phases when building several resident buildings." Interviewee # 10

When discussing how learning and experience from the measurements could, and should, be used subsequently, the professor from NTNU stated that it is challenging to compare performance measurements and numbers on productivity across projects, companies, and industries. This is due to the complexity in implementation, context, and solution. Hence, in many situations, it might be wrong and challenging to "compare apples and oranges". He also highlighted the fact that it is easy to misuse the metrics and the resulting numbers. This exemplifies why it is important to know and be aware of what lies behind the numbers in order to be able to use them in a sensible way. Additionally, if this is not done properly, then one can easily create myths and a distorted picture of the measurements.

4.2.3 Implementation issues and informal conditions

This subsection describes the findings from our empirical research and addresses the different attitudes towards, and knowledge of, performance measurements, and how this influence the implementation process. This is then followed by how the informal conditions and barriers could affect the measurements, and the participant's views concerning how performance measurement influences their work climate and culture.

4.2.1.3 Attitudes towards, and knowledge of, performance measurements

The most important aspects concerning the different attitudes toward performance measurement will be presented in this subsection. Our findings revealed that there are various conditions, which could influence the participants' attitudes and views of performance measurements. There are several distinctions in viewpoints and opinions concerning this particular topic, but there are also some common arguments that are somewhat consistent with the overall understanding and perception of the purpose to why one should, or should not, measure performance.

> *"It is good for the industry to bring in more measurements." Interviewee # 12*

There are, however, divergent opinions regarding the ability for performance measurement to drive productivity and create improvements for the industry. One of the interviewees point to their payment system, arguing that "it is a payment-based system based on performance, you are being measured all the time." Interviewee # 12. Followed by the statement that: "it is just numbers that float around and does not make any sense" interviewee #12, obviously negatively affected by the way that these measurements influenced his job. Another significant finding from our research was that most of the interviewees had the impression of measurements being valuable for not only the present but also for future projects. However, this view was not shared by all the participants, and some of the interviewees implied that performance measurement would not "come in handy" for them arguing that "It doesn't really matter to me, we are just following the weekly work plan, and if we can do so, then everyone is happy." Interviewee # 11. Additionally, some of the interviewees were questioning the purpose of documenting the results from the measurements, whereas one of them argued that he did not understand how performance measurement could be beneficial, since every project is unique, and so will the execution and challenges related to it be as well.

It came clear during both observations and interviews, that several of the participants had a good technical understanding, and that they had access to and used different systems and programs for both project planning and technical drawings. However, a common concern among the interviewees was that many of them did not understand how to perform this type of measurements and neither spent time nor energy figuring how they should do it. Another interesting finding was that some of the interviewees had the impression that since they were over a certain age, they would not have the benefit of learning something new, admitting that they felt "a bit old to understand all of these new systems. It should be handed over to the youth to handle." Interviewee # 5.

During our observations, we observed that there was a great variety in what the different participants used as an overview of the technical drawings and the project plan. It is not compulsory to use MS project and other digital tools for this purpose, and it was stated by several that as a result, it was spent time and resources on cross-checking that everyone based their work on the same plan.

"I have not yet found any tools that can measure it." Interviewee # 8

"We realize the value of it and are aware of the need but have not figured how to do it yet." Interviewee # 12

One of the interviewees explained that his interpretation of the LPS was strongly influenced by Greg Ballard's early statements regarding the level on the different metrics. He had supposedly argued that the reason why the goal of PPC should not be equal to 100% was that it might indicate that the workers were underloaded with work. For our interviewee, this did not make sense, why should one aim for a goal that is not 100%. Ballard did, however, acknowledge this reasoning and subsequently changed his mind. After discussing with Ballard, our interviewee did now recognize the purpose and potential benefits of the LPS. Nevertheless, he has not yet participated in performing any measurements of this type in any of the projects he has been a part of.

The literature emphasizes that there are both behavioral and organizational challenges related to performance measurements (Lantelme & Formoso, 1999. During our observations and interviews, several confessions and concerns were revealed related to how individuals would perceive the process and results of the measurements. The majority of the interviewees agreed that if the measurements were used with the wrong intentions, the effect would have negative consequences, such as e.g. poor motivation. One of the interviewees argued that it is important that the numbers are used as indicators and not for explicitly defining if someone is doing a good job or not. This statement was also supported by one of the project managers, who argued that when measuring an individual's performance, one actually measures how fast they work. Thus, the workers could get the impression that they are not working "fast enough".

The professor from BI explained that in a "performance climate," one is encouraged to collaboration and mutual exchange of ideas and thoughts. The emphasis is placed on the simplicity of learning and developing, where workers are encouraged to try new methods and solutions in their work processes. On the other hand, in a climate where "the result" is the main focus, work performance is measured based on a comparison between colleague's performance. This type of internal competition encourages achieving the best possible result, and only those who perform best are acknowledged. He further stated that research had shown that there is a positive correlation between this type of climate, burnout, and high turnover. While, on the other hand, "performance climate" proves to be positively related to work engagement, commitment and motivation and negatively related to burnout and high turnover.

Regardless of which metrics are being used to measure performance, several interviewees emphasized by that it is important to be aware of the human conditions when communicating and presenting the numbers. One of the project managers explained that he, in order to not be misunderstood, felt forced to keep the numbers hidden, arguing that "some numbers could be harmful", and is therefore important to take into consideration in order to avoid any misleading interpretations. As a result, instead of presenting the numbers as statistics by emphasizing a quantitative approach, he chose to make it a qualitative process, by focusing on potential improvements and strategic prioritization of time.

It is a clear consensus among the interviewees that performance measurements are useful to increase productivity. However, according to some of our interviewees, there are important preconditions and assessments that must be agreed on. Several of the interviewees raised their concerns regarding the cultural aspect. Even if performance measurement were deemed important to achieve greater productivity, the degree of trust, involvement, commitment, and a common understanding is important when performing this type of measurements.

"You must have something common as a base, to ensure that everyone shares the same language, understanding and that they have the same perceptions." Interviewee # 14

One of the participants concluded that if it negatively affected the working environment, it was not "worth the while." Additionally, some interviewees emphasized that a common cultural understanding is important to have in place in order to fully exploit the potential advantages of performance measurement. Additionally, enhancing performance measurements involves motivating everyone to improve upon past performance, not only those who are the most capable or talented workers.

The importance of having a common understanding of the purpose behind the measurements is recognized by several of the interviewees. There was a shared explicit view that it had to be a misconception of the purpose of measuring if the measurements were conducted only for the reason of collecting numbers. These reflections were supported by other representatives from both Veidekke and the other construction company and illustrate the importance of the cultural conditions and perceptions that underlie the performance measurements. This was exemplified by one of the project managers, who highlighted that: the rationale behind measurements is not related to the ability to expose someone, or tries to compare, based on "one's ability to run fast." On the contrary, the intention is to identify areas for improvement.

"You do not measure only for the purpose of measuring, and to see if you have achieved a goal or not. The purpose of the measurements is to make sure that you make the right choices along the way." Interviewee # 6

Another important aspect is the experience of being measured, hereunder the need for confirmation and acceptance of doing a good job. It was stated by one of the project managers that he had cross-cultural experience working with Lean in the construction industry, and had, among other places, been traveling several places in the US and Asia. He explained that in these areas, numbers and statistics on performance are quite common, if not expected, to be openly communicated. However, the work culture in America and Asia is utterly different than it is in Europe, especially compared to Norway. He, therefore, explained that this would not be the case for the Norwegian construction industry, arguing that "while in Norway, it is not so culturally accepted." Interviewee # 1.

"I had a feeling that people preferred, or did not want to, be measured. We did not manage to get good measurements on the PPC and had to explain that it is all about how good we are to plan, which might be a bit hard to understand." Interviewee # 2

On the other hand, other interviewees believe that this is not only related to cultural differences, arguing that the challenges of performance measurement are much grounded in the fact that "it is challenging simply because we are humans, and we are not so found of measuring." Interviewee # 2.

In sum, our empirical findings indicate that a major part of the challenge with implementing and using performance measurement was related to the lack of knowledge. Our research revealed that there is no given formal system to do performance measurements in CPM projects. Although PPC is a part of one of two guidelines at Veidekke, there are no tools or explanation on how to implement these in their project. Additionally, the other LPS metrics (TA & TMR) are not mentioned in any of the workbooks, nor commonly recognized by the interviewees, although most of the reasons for deviation are related to the poor performance of TA and TMR. With regards to our second research question, several interviewees acknowledged the value of performance measurements in their construction projects, there were some contra arguments that it would be excessive concerning their type of project, where they are in the production phase and insecurities of the value gained versus the amount of resource devoted to measuring.

5.0 DISCUSSION

This chapter will elaborate and discuss the empirical findings and analysis from chapter 4 in relation to the theoretical background presented in chapter 3. We have made a thorough comparison by combining the different areas of our findings with the relevant issues from prior research and literature.

In order to further investigate the literature gap in performance measurement within the context of Lean Construction, we have decided to investigate both the formal and informal aspects of this interplay. The theoretical background and our empirical findings address several interesting aspects, we have, however, chosen to extract the most relevant and significant findings to answer our research question. This chapter will follow the same outline as in the theoretical framework (Figure 6) and will be based on the same central- and sub-themes, as presented in section 2.4 (Table 2). Our discussion will firstly address the formal conditions and implications of how performance is measured, based on our empirical research, and how it is implemented in consonance with the theory. This is then followed by a discussion of our major findings regarding the challenges and implications of performance measurement, focusing on the informal conditions. Lastly, based on the above reasoning, we will consider the relevance and rationale of measuring performance in Lean Construction.

5.1 How is performance measured within Lean Construction?

Previous studies have shown that Lean Construction is understood and interpreted differently across the industry, which our findings during observations and participation at Lean Construction seminars can confirm (Green & May, 2005; Pettersen, 2009). Although Lean thinking has been emphasized in construction projects for a while, there is still inconsistency between academia and how it is implemented across the Norwegian construction industry. The result is that the interpretation of Lean is primarily based on implementing tools and concepts rather than the business philosophy itself (Saurin et al., 2013). Perhaps, this is due to the challenges concerning the conceptualization and terminological vagueness of Lean Construction (Alves et al., 2012; Jørgensen & Emmitt, 2008; Pettersen, 2009). Our study indicates that there is different terminological take on Lean Construction by

Norwegian construction companies. For instance, Veidekke uses the term "Collaborative Planning in Design and Production Management," whereas AF-Gruppen has adapted its definition of Lean Construction into Virtual Design and Construction. Despite this lack of consistency, there are nevertheless some elements that seem to be key in Lean Construction.

Lean thinking forces the focus on optimizing the project in its entirety, rather than having each actor concentrating on optimizing their part in the construction project. Therefore, Howell (1999) argues that if all of these actors work together towards a common goal, the result of the project can be greater. As research has shown, the LPS play an important role in Lean Construction, although it is just a part of the overall business philosophy. This is an important factor that seems to be easily forgotten based on our findings and observations. Thus, this hampers the ability to fully improve the performance. Our study shows that there is not a unified understanding of CPM amongst interviewees within the same project and across projects. For instance, Veidekke allows for different approaches when it comes to the applications of tools and systems, as the practitioners are given a choice to whether partly or fully take use of the CPM methodology. However, this is not in accordance with Lean thinking, where one should not get such a choice. It should rather be implemented as a business philosophy where this methodology is a part of Veidekkes culture and conceptualization of this methodology is commonly acknowledged, in order to facilitate for continuous improvements (Alves et al., 2012; Green & May, 2005; Jørgensen & Emmitt, 2008; Sage et al., 2012; Saurin et al., 2013).

Research demonstrates that a lookahead plan would enable the project managers to get a good overview and help them map potential obstacles (Ballard & Howell, 1994a). Our study indicates that this plan could be improved by enhancing VSM, which would also facilitate the prerequisites of Lean thinking in construction projects. VSM is deemed to be a useful methodology when analyzing whether activities in both the production and design plans are value adding or non-value adding. Perhaps, combining this methodology with the LPS would enable continuous improvements while reducing waste and non-value adding activities?

5.1.1 Performance metrics in the LPS

Our research indicates that there is no commonly acknowledged performance metric adapted in a systematically and consistent matter in the construction industry (Langlo & Andersen, 2016). Furthermore, based on Powell's research (2004), there seems to be a challenge to decide on which metric to use. This is in line with our empirical findings which imply that there is a lack of understanding on how to define and measure performance, which indicates that there is some insecurity on which metrics to use and how to implement them in the project.

Although the LPS metrics are the most commonly used to measure the productivity in Lean Construction (Fischer et al., 2017; Kalsaas, 2017), our empirical findings show that some challenges occur when these are being used separately. This finding is confirmed by Chew (1988) and Crawford & Vogl (2006), who emphasized that using only single factor metrics could be misleading, and therefore argued that a multi-factor index could enable managers to see the overall picture. This is in accordance with our empirical findings where most of the interviewees were missing one single index that covered several aspects of the performance, both the measurable and unmeasurable factors. Unmeasurable factors are factors that cannot be captured by the LPS metrics, e.g. outputs and inputs from the support functions, such as how good the managers are to update the lookahead plan based on changes and challenges that occur (Ballard & Howell, 1994; Liu et al., 2010). However, these factors would significantly influence the measurements of the disciplines. It is therefore questioned whether the performance measurement can be viewed as a value-adding activity if these factors are not addressed in the process.

Prior research has found that there is a significant positive relationship between measuring PPC and productivity in the project (Liu et al., 2010). However, our research revealed that there was some skepticism regarding implementing and using metrics, such as PPC, for measuring performance. Although PPC could improve productivity, Ballard and Tommelein (2016) claimed in their study that PPC could be equal to 100%, while the project could still be falling behind schedule. This could also be related to Modig & Åhlstrøm's (2018) discussion regarding the efficiency paradox, where they argue that getting a particular task carried out efficiently will not indicate that the project is carried out effectively. For this purpose, PPC could accentuate good efficiency, but this does not, however, mean that the project is effective.

Our observations and findings revealed that there are often activities that occur throughout the project which are not planned for, such as rework when a discipline has not fully finished their work according to procedures. Such non-value adding activities are not captured by the PPC metric, which could encourage the discipline to focus on optimizing their own work rather than the entire process since their individual performance would be at stake (Modig & Åhlstrøm, 2018). As mentioned by some of the interviewees, they have a performance-based salary at Veidekke, and to increase their salary per hour, they tend to not prioritize time to any additional work, such as cleaning and removing waste from the workplace. It could, therefore, be questioned who´s PPC measurements this should affect when some disciplines must carry out such non-planned activities that are not specified for anyone particularly.

Prior research suggests that a work breakdown structure should take place to increase the possibility of flow efficiency (Ballard & Howell, 1994a; Modig & Åhlstrøm, 2018). This is in line with our findings where the interviewees recognized the importance of removing barriers for each activity and involving the discipline in lookahead planning. Thus, it is found reasonable that TA and TMR should be emphasized more. TA measures how well each activity in the plan is anticipated, whereas TMR measures how well each activity is made ready for execution (Ballard, 1997; Hamzeh et al., 2015a; Hamzeh et al., 2016). Our research revealed that most of the interviewees did not have a clear understanding of the different metrics within the LPS. PPC was the only metrics which seemed to be commonly known amongst the interviewees, whereas TA and TMR were only recognized by one of 15 participants at Veidekke. The reason for this could be that PPC was the only metric presented and emphasized in one of their CP guidelines and mentioned in the introduction course. Although they do not directly measure TA and TMR, it was found that almost every project dedicates some time to discuss these aspects every week. It could thus be questioned whether it is necessary to measure how good they are to anticipate the tasks and remove obstacles. However, as previously mentioned, Chew (1988) argued that a single factor metrics is not enough to see the overall picture, and thus TA and TMR, aligned with PPC, is necessary to do in order to achieve improvements. Previous research has proved that the TA has a positive impact on the reduction of the project duration (Hamzeh et al., 2015b). It is, therefore, reasonable to assume that both TA and TMR could, to some extent, measure the support functions´ productivity. Moreover, our empirical analysis of the data indicates that the initial reason for deviation was related to a lack of reflections concerning TA and TMR, which then again affected the PPC measurements negatively, e.g., reporting and devoting reasons for deviations from the lookahead and weekly work plan. Overall, this indicates that by emphasizing metrics such as TA and TMR, one could avoid low PPC measurements.

In sum, from a theoretical perspective, the literature indicates that the PPC metric captures the most important aspects of the measurement regarding the different activities. However, our empirical findings reveal that there are some implications regarding the PPC metrics that must be addressed.

5.1.2 The importance of implementation and evaluation of performance measurement

In this subsection, we discuss how performance measurement is or should be implemented with respect to formal structures such as tools and systems that are required. This is then followed by a discussion of the process of learning and exchange of experience.

Previous research has emphasized that a commonly used approach to measure is a prerequisite found essential for involving the organization for successful implementations (Aslesen & Tommelein, 2016; Ballard & Howell, 1994a; Chew, 1988; Langlo & Andersen, 2016). The professor from NTNU even stated that any productivity measurements system is only helpful if it is used in a holistic way, which is also supported by prior research (Chew, 1988; Porwal et al., 2010). However, our research revealed that there is inconsistency in the way they measure the performance at Veidekke, although the majority of the interviewees desire a shared performance measurement system. Moreover, Langlo & Andersen (2016) recognized the importance of this in their research, where they concluded that performance metrics need to be implemented and used in a systematic matter in order to reveal if the performance fall or improve over time during the project process. Our observations and findings indicate that the project managers if they measure consistently and adequately, are able to track uncertainty and take corrective actions, which would perhaps improve the flow efficiency. This is also supported by research, which argues that performance measurement could be used as a systematic way of judging project performance (Forsberg & Saukkoriipi, 2007; Modig & Åhlstrøm, 2018; Star et al., 2016). An example of this is how AF-Gruppen uses the digital platform "Touchplan" for both planning and measuring performance, and state that this enables them to achieve their desired goals. While it seems like the existing system at Veidekke, tend to be based on coincidence and prior knowledge of the tools and systems that could be used to measure performance.

Based on Bernstein's research (2012), another important takeaway is that transparency across the hierarchical levels is viewed upon as an essential factor, which is easier to accomplish with a shared system in the organization. However, the same research argues that if the transparency of the results were used in a poor way, this would inhibit productivity. Yet, some of the interviewees' states that they would like to use performance measurements to expose the different disciplines when they are not performing according to the project plan. However, those who actually measure performance have stated that they would rather use performance measurements to increase the motivation of the subordinates. Moreover, Sacks and Harel (2006) states that it is more likely that subcontractors would assign resources if they were able to participate early in the project-planning phase. This can, therefore, confirm that there are different viewpoints on how to use the performance measurement. This provides insight on how communication of the results from performance measurement could create insecurity for those individuals that do not have an understanding of what the metrics indicate.

In their research, Barbosa et al. (2017a) argue that implementing Lean principles could be the solution in order to improve the productivity stagnation through reducing waste and variability in the project planning and coordination. In addition, some researchers have claimed that by conducting performance measurements, it is possible to identify areas for improvements (Fosse & Ballard, 2016; Hamzeh et al., 2009).

Prior research argues that it is possible to identify areas for improvements through measuring performance (Fosse & Ballard, 2016; Hamzeh et al., 2009). According to Ballard and Howell (1994b), measuring performance can contribute to improvement in planning. In addition, a thorough root-cause analysis of why there is non-completion of activities or deviation from the plan could for prevent repetitions of these (Ballard & Howell, 1994a; Ballard, 2000; Koskela, 1992). This is supported by our research, where the empirical findings and observations indicate that performance measurement is used for continuous improvements in the project, e.g., when someone repeatedly forgets to order materials. We also found in the quantitative analysis that the trend in reasons for deviation was more frequent from the middle of the project execution, and especially the more disciplines that were involved, or active in the given project phase. We believe this emphasizes the necessity of having structured systems and consistently measuring performance while continuously updating project plans throughout the whole project process.

Based on our research, some of the interviewees explained that they used performance measurement to prioritize their time on those disciplines who struggle. In order for continuous improvements, one cannot solely focus on those disciplines that are facing a hard time, but instead focusing on the overall project. Thus, we believe it could be questioned whether this is the most optimal way of using performance measurement.

Previous research has argued that performance measurement could help to identify root-causes for non-completion or challenges that occur during the project execution (Ballard & Howell, 1994a; Ballard, 2000; Koskela, 1992). However, some of the interviewees questioned if this would create the value of any matter, given that each project is unique and most of the challenges that occur are project specific. Our empirical findings indicate that the performance measurement recordings could provide an "experience database" for the next projects, where it is easier to understand the main reasons for deviation. These could provide an indication of which aspects that need to be addressed in order to improve flow efficiency.

In addition to the importance of having consistent systems and tools for measuring performance, it is found in our research that how the measurements are subsequently analyzed and used as a mean toward improving performance is just as important. Our findings reveal that due to people's fear of measurement, the metrics might consequently end up inaccurate and manipulated to make sure that the targets are achievable and that there is no blame to be distributed (Powell, 2004). This change of behavior could also reduce the initial value of the results. Furthermore, how each deviation is defined could provide different results, which we will discuss further in section 5.2.1.

5.1.3 Who should be responsible for measuring performance?

Our research shows that the majority of the interviewees would delegate the responsibility of measuring the project performance to the middle-level managers such as the project manager, construction manager or construction foreman, also defined as the last planner (Aslesen & Tommelein, 2016; Ballard, 1993). This is in accordance with Koskela's (1992) research, which emphasized that management commitment and involvement is essential when implementing a new philosophy, such as performance measurements. However, previous research has shown that many managers fear that their lack of knowledge would be exposed, which could affect their initiative to make use of performance measurement (Ashton et al., 1990). This is confirmed by our empirical findings, which indicate that this is dependent on whether an individual is capable of using digital tools and systems and understands the different metrics in the LPS and how they interplay.

Our research revealed that there is a great variety of involvement for some of the disciplines and subcontractors and that the degree of involvement in the evaluation process was not as desired. Therefore, some of our interviewees argued that they would not want to take personal responsibility if their performance is not according to the productivity goals set by the management team. This illustrates that "top-down" performance measurement, i.e., project managers evaluating foremen's performance, could hamper the motivation for improvement if the degree of involvement is limited. This is in accordance with the research of Powell (2004) where Neely explains how disappointing data from performance measurements turns out to be used in an intimidating and judgmental way by the management, and often could encourage for defensive behavior. This was also supported by Sacks and Harel (2006) who in their study revealed that subcontractors were more likely to devote resources into projects where they were involved early in the planning phase, as opposed to projects that were perceived as more unpredictable. The challenge seems to be related to the implementation of the systems and arises from the fear of measurement and what the metrics might indicate, and how this could influence each discipline or individual. Perhaps, involving the disciplines to a greater extent would increase their motivation for productivity improvements, where they can take responsibility and control of their activities (Koskela, 1992; Mossman, 2009; Sage et al., 2012).

In our research, some of the interviewees uttered a negative attitude towards being measured but would however like to measure their subordinates in order to gain better insight into how they are performing. Therefore, our research questions the validity and reliability of the collected data based on the individuals that are responsible for measuring. This is related to our empirical findings which verifies that the challenges occur when the middle managers who are responsible do not always prioritize time, especially if they do not have a complete overview of the project progress. On the other hand, trust is an important prerequisite if each discipline is responsible for reporting these numbers. If there is a lack of trust and commitment, there will be a need for someone to control that they are performing to what has been reported. It would also entail that there is a greater need to understand the purpose of performance measurement, but also concerning tools and systems used to measure performance.

5.1.4 Informal conditions affecting performance measurement

By conferring previous research, it becomes evident that both the formal structures and informal conditions play an important role in performance measurements (Green & May, 2005; Sage et al., 2012). Although structured and systematic methods and tools are vital for measuring performance, our empirical findings and theoretical framework shows that several conditions affect performance measurements in Lean construction. The informal conditions emphasize the awareness of attitudes, behavior, and cultural aspects.

Previous literature highlights that the purpose of measuring performance is related to the process of identifying potential areas for improvements and to influence behavior (Ballard & Howell, 2004; Beatham et al., 2004; Deming, 1968; Fosse & Ballard, 2016; Robinson et al., 2005; Star et al., 2016). In our research, we found that a common concern among the interviewees was related to how the results of the measurements would be used. It was a clear consensus amongst the participants that the numbers itself could encourage unwanted behavior or influence motivation negatively if they are used to expose disciplines or individuals. This is in line with previous research where Neely (Powell, 2004) emphasized that due to people's fear of measurements, metrics end up manipulated and inaccurate. In addition, this was exemplified by one of the project managers who highlighted that the rationale behind performance measurement often gets misunderstood. Instead of being interpreted as indicators meant for identifying areas for improvement, individuals could experience it as a way of measuring individual performance based on how fast they are working. Based on our empirical findings, we see that it is important to emphasize a culture, which is based on trust, commitment, and a common understanding of the purpose behind the measurements. In this sense, the professor from BI explains that focusing on developing a "performance climate" could encourage and motivate the workers to aim for best results, positively affect work engagement, and reduce burnout and high turnover.

Locke & Latham (2009) argues that there is a positive linear relationship between goal difficulty and task performance, where the hard goals turn out to produce a higher level of performance than easier goals do. PPC measurements are statistical numbers which, arguably, indicates how efficient the different disciplines are, meaning that PPC = 50% indicate that a discipline accomplished 50% of the planned activities. It was stated during one of our interviews that if the goal of measuring PPC was now equal to 100%, then the purpose of measuring it was absent. On the other hand, in their research, Ordóñez et al. (2009), argue that the systematic side effects of over-prescribing goal setting are far more systematic and serious than prior research has acknowledged and that the damaging effect of goal setting outweighs the benefits. This is consistent with our empirical findings, which showed that the purpose of performance measurement was missing if the disciplines perceive the measurements as "simple" statistics instead of means of identifying areas of improvement.

The numbers are meant to be used as indicators, not as an opportunity to expose or single out anyone (Powell, 2004). This can be related to Bandura's research (1982, 2010), which defined self-efficacy as an individual belief in one's ability to accomplish a task or succeed in specific situations. In his study, Bandura argued that individuals with high self-efficacy would perform better with a higher likelihood of successful outcomes, whereas individuals with low self-efficacy are more likely to fail. Empirical findings from the study indicate that high self-efficacy is an important prerequisite in order to achieve the desired outcome of performance measurement. Meaning that for performance measurement to be successfully implemented, one has to avoid that it gets used with the wrong intentions and that it does not affect or influence motivation and/or behavior negatively. In this regard, mutual trust between the disciplines and those who are responsible for measuring is crucial in order to achieve the potential benefits of high self-efficacy. If high self-efficacy is achieved amongst the construction workers, prior research argues that this will positively influence work-related performance and should thus be of importance when conducting performance measurement in Lean Construction (Stajkovic & Luthans, 1998).

Our findings indicate that although several of the interviewees expressed their belief in the benefits of performance measurements, there seems to be an overall fear of being measured. It was stated during interviews that this was related to the fact that "we are only humans; we do not enjoy being measured." The majority of the participants claimed that they would agree to perform measurements, but they did prefer, however, not to be measured themselves. The goal of performance measurements in Lean Construction is to establish a common ground which facilitates for commitment, trust, and respect. Thus, it is important to have the right attitude amongst those who are responsible for measuring performance.

Bernstein's research (2012) found that increased privacy significantly and sustainably improves performance and that it is an important factor in continuous improvement, productive deviance, avoidance of distractions, and experimentation. Our empirical findings indicate that there were different views regarding the scope and complexity of measuring, and it was questioned if excessive measuring could eliminate the advantages of measuring performance. Based on Bernstein's (2012) findings, one could argue that the process of obviously recording every action for discipline rather emphasize the opposite than what was intended. Which is also in line with Neelys arguments (Powell, 2004) upon people's fear of measurements. This leads us to another important aspect to consider, which is how the results from performance measurement are subsequently used towards the different disciplines. In his research, Behn (2003) argues that it is neither the act of measuring nor the resulting data which will generate results; it is only when they are exploited that they will accomplish satisfactory results. This statement is supported by several researchers, whereas the professor from NTNU, further argue that measuring performance only for collecting numbers is a waste of time, and would lead to misjudgments, and thus not provide any value (Fischer et al., 2017). This means that without properly utilizing the collected data from performance measurements, one will not achieve the desired results. Also, when presenting the findings based on the performance measurements, one must be aware that individuals perceive feedback differently. Informal conditions such as commitment, trust, openness, and a common understanding of the purpose behind performance measurement play an important role in this process. The relevance of performance measurement greatly depends on the individual who is conducting and presenting the measurements. As such, it is important that whoever is responsible for conducting the measurements is aware of their responsibility and impact on the working environment.

5.2 Why, or why not, should performance be measured in Lean Construction?

Sage et al. (2012) state that companies who base their operations on Lean thinking need every actor to get involved and actively participate in the collaborative activities on where Lean methods and tools are founded. In sum, it can be argued that in order to communicate and adapt the performance measurements in a construction project, more attention must be given to understanding how this is in accordance with Lean thinking in order to improve the current project execution. Because the theoretical background and empirical findings capture many interesting aspects of why, or why, not performance measurement should be performed within Lean Construction, we chose first to discuss the interplay between performance measurement and productivity, followed by the views and knowledge of performance measurement in the Norwegian Construction Industry. Lastly, our discussion will address whether time spent on performance measurement is a value-adding activity, according to Lean thinking.

5.2.1 The interplay between performance measurement and productivity

Prior research emphasizes that productivity, or the lack of productivity, is a major challenge facing the construction industry for the last decade (Barbosa et al., 2017b). Several researchers argue that the productivity growth in the construction industry is significantly lower compared to other industries (Allmon et al. 2000, Force & Britain 1998; Miller et al., 2009; Barbosa et al., 2017b). As a result, more attention is drawn towards figuring how to counteract this stagnation and finding ways to make productivity improvements in the construction industry (Aziz & Hafez, 2013; Bertelsen, 2004; Koskela, 2000). Our findings revealed that the majority of the interviewees have the same view as prior research, but that academia, however, does not take into account an important aspect that influences the statistics. When discussing productivity, the construction industry often gets compared to, e.g. the improvements industrialization did for the car industry. The question is, however, how fair this comparison is since these are two quite different industries.

As stated by literature, in the construction industry, it is the workstation that flows through the product, while in series-production, it is the product that flows through the workstations (Kalsaas, 2017). This means that the process of improving productivity in these two industries is based on quite different factors. A common denominator is that both industries aim to improve and optimize the production but also the flow between the workstations. It is, however, important to be aware of the impact of the industrialization that has taken place in the construction industry. The industrialized construction provides benefits of repetition and simplifies site processes but is, however, more vulnerable and complex. This is because the production process is using two locations, both factory, and site, which increase the need for coordination, e.g. requirements for dimensional accuracy of the prefabricated component (Koskela, 1992). Our empirical findings reveal that field experts and researchers tend to not take into consideration the different parts of the construction industry that has been industrialized, e.g., prefabrication of bathroom cabins. Thus, it does not capture the actual beneficial impact that industrialization has on productivity in the construction industry. This was a topic of much debate amongst several of the interviewees, who expressed concern that an excessively narrow focus on only particular parts of the industry hampers the actual results of innovation and new technology on productivity.

Increased attention has been given to the different techniques and tools of Lean Construction in the Norwegian construction industry, and some concerns recur in our research with regards to the introduction of the different measures implemented. Our findings indicate that there is a lack of knowledge of the purpose of performance measurement, especially considering what role performance measurements play in increasing productivity in the construction industry. This is also in line with previous research where Crawford & Vogl (2006) argues that there seems to be no consensus about how to investigate the productivity performance in construction projects, despite the existence of well-developed frameworks. Moreover, Womack et al., (1996, 2007) concluded that performance measurement is not worthwhile to execute. Instead, they argue that companies should focus on improving performance and process by implementing Lean techniques. The question is, however, if performance measurement can be deemed as a method within Lean Construction that can improve productivity by increasing flow efficiency and facilitate for continuous improvement.

The professor from NTNU expressed his concern regarding how the metrics easily could be misused or used incorrectly. Accordingly, an example we would like to present was the fact that since the PPC metric is quite simple, and only contains *planned* and *finished* tasks, it does not grasp other important elements of the different activities. In our analysis of the PPC measurements from both Frysjaparken and Hagebyen, we see that a substantial part of the measurements does not capture either cost or risk of the different activities. Accordingly, the measurements could be easy to manipulate by dividing one activity into multiple activities, as seen in, and in that way, achieve higher PPC than by initially following the plan. This finding is also supported by prior research, which emphasizes that metrics could end up inaccurate and manipulated if the numbers are communicated in such a way that they single out disciplines or individuals (Powell, 2004). This is both critical and problematic in that sense that the measurements could indicate that activities are according to plan, since the results are high, but the truth might be quite severe. Following, if this week's plan initially includes in total 4 activities, whereas activity 2 and 3 are each, respectively, very costly and risky, and activity 3 can be divided into two separate activities when reporting to those responsible for measuring. On the other hand, activity 1 is neither very costly nor risky and is easily separated into three different activities, whereas activity 4 is both very costly and risky, and the complexity of it makes it hard to divide into multiple activities. For the sake of simplicity we can divide the case into two scenarios: if we say that activity 1, 2 and 3 are completed, while 4 is not completed, scenario 1 will have a total of 4 activities, where 3 out of 4 activities are completed, and the calculated PPC is 75% (3/4). While in scenario two, there is a total of 7 activities where 6 out of 7 activities are completed, and the calculated PPC is equal to 86% (6/7) following the rationality as described. This indicates that one will achieve higher PPC due to manipulation of the calculations of the different activities. However, these activities are not as critical, related to cost and risk, as activity 4, therefore the PPC will be inaccurate considering the importance of these aspects. Put somewhat extremely, if activity 4 consider roof sealing, and activity 1, 2, and 3 are mainly indoor work related to list-work and painting. If then, activity 4 is not finished or completed satisfactorily, it would not be either reasonable or even possible to activity 1, 2, and 3.

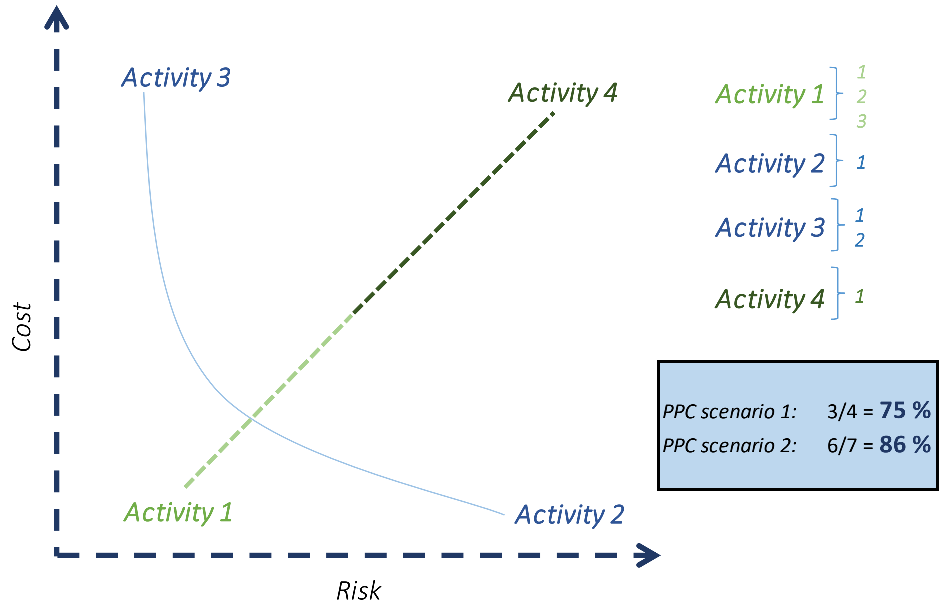


Figure 21: Cost and risk of each activity

However, it is important to emphasize a culture that works towards using performance measurements as an initiative to identify areas for continuous improvement and learning. In this regard, trust and commitment play an important role in achieving the desired outcome of the measurements. For this reason, it should not be a motivation to manipulate the different activities as in the example described. However, the possibility of manipulating the number is important to be aware of. Additionally, this type of analysis or awareness could serve useful for those who want to extend and develop their methods for measuring performance but should maybe not be demanded by companies or project teams who have not included any measurements earlier. This is because they should emphasize to implement the different suggested metrics before making more complicating calculations and analysis.

5.2.2 The views and knowledge of performance measurement

The presented literature highlights several different perspectives regarding the process of measuring performance in the construction industry. Prior research argues that performance measurement plays an important role in providing necessary process transparency and that by developing and implementing a balanced set of measures, business performance can be enhanced (Bernstein, 2012; Lantelme & Formoso, 1999; Kaplan & Norton, 1992; Neely et al., 1996). The majority of the participants seem convinced that performance measurement, in one way could suit useful for identifying areas for improvement. However, our empirical findings show that there are divergent opinions regarding the ability for performance measurement to drive productivity and create improvements for the industry. A general impression amongst several of the participants was that performance measurement could be useful as a control element, and it was stated that they would like to measure the performance of their subordinates, but that they, however, did not want to be measured themselves. This is supported by our findings, which indicates that the fear of measurements seems somewhat related to the experience of being controlled and monitored.

A notable observation was that despite the conscious aim to improve and streamline both production and planning, several of the participants dismissed the responsibility of getting familiarized with new technology and systems for performance measurement, due to their age. Prior research emphasizes that a precondition for efficient Lean implementation is that there is a collective understanding of the concepts behind Lean and that the process of implementing Lean Construction is sustained with a culture of continuous improvement (Aziz & Hafez, 2013; Fischer et al,. 2017; Freire & Alarcón 2002; Green & May 2005). It is therefore important to be aware that the process of initiating measures for improvements, even if these are performance measurement or innovations, is highly depending on the project manager's efforts and commitment (Mossman, 2009; Sage et al., 2012). This should not be influenced by other incentives related to personal perceptions, such as the limitation of age. The literature emphasizes that the construction industry is a unique industry where field experience is an essential factor in maintaining high levels of productivity (Dozzi et al., 1993). We, therefore, find it reasonable to argue that instead of focusing on age as a limitation against implementing systems for increasing productivity, one should acknowledge the opportunity of combining unique experience and knowledge in the implementation process.

Our research also shows that the majority of the participants seldom or never use any of the metrics from the LPS, either within production or planning. It became evident that many of the interviewees had the interpretation of performance measurement as especially complex or advanced systems of measurements, or that they just did not understand how to implement or perform any performance measurements. Although several of the participants were familiar with the LPS, PPC was the only metric which was used for those who did perform any performance measurement. According to Porwal et al (2010), one of the main challenges faced during the use of LPS is due to only partial implementation. However, theory highlights that even partial implementations provide substantial improvements (Ballard & Howell, 2003). As we will discuss later in this chapter, the approach of measuring PPC is quite straightforward, especially compared to many of the more complex and technical systems which are used.

5.2.3 Is time spent on performance measurement deemed a value-adding activity?

The Lean Construction literature repeatedly emphasize that time should be spent on minimizing waste and non-value adding activities in construction projects, while at the same time seeking to optimize customer value (Kalsaas, 2017; Koskela, 1992). Our findings demonstrate that the time aspect was a decisive factor amongst several of the interviewees, and a common concern was that performance measurement would be a time consuming and non-value adding process. An important aspect to consider is that there must be a common understanding of the purpose behind performance measurement in order for the measurements to provide the value necessary to defend the time spent. This leads us towards the discussion of whether performance measurement is deemed a value-adding activity, or not.

Prior research emphasizes that performance measurement provides an impression of where we are, and where we are heading, and will in that sense create feedback on the effectiveness of improvement interventions (Cohen & Levinthal, 1990; Leong & Tiley, 2008; Liebowitz, 2004; Rose, 1995). Other researchers argue that metrics are essential in order to understand and, if needed, correcting team performance during the production (Fischer et al., 2017). Our findings indicate that the majority of the participants acknowledge the potential value of performance measurement, but that several prerequisites have to be accounted for in order for it to be consistently perceived as a value-adding activity.

The principles of Lean basically involves continuously working towards identifying and eliminating waste, towards leaving only activities that are value adding in the value stream (Rother & Shook, 2009). The literature also highlights that in order for performance measurement to be a value-adding activity, it has to provide more added value than it would if time was prioritized differently (Ballard & Howell, 2004; Bjørnfot & Stehn, 2007; Lindfors, 2000). A general perception amongst the interviewees is that performance measurement is a time-consuming and comprehensive process, which requires much re-prioritization of time. Hence, the performance measurements have to deliver corresponding to the expectations in order to be perceived as appropriate prioritization of time. According to our findings, those who have successfully implemented and used performance measurement in their projects experience that it is through measurements they are able to identify potential areas for improvement. It was also stated that, if used properly, one actually saves time doing measurements, which means that a potential benefit of performance measurement, correlated to Lean thinking, is the possibility of reducing time spent on non-value adding activities. This reasoning is supported by findings from our quantitative analysis, which shows that by analyzing the different reasons for deviation (as seen in Figure 15 and Figure 16), the project manager can differentiate between the deviations and focus his time on the areas that need improvement. Our empirical analysis illustrated that *information,* *connecting activity*, and *workers* account for 72 – 87 % in total for deviations in the weekly work plan, improving these would, therefore, have a significant and visible effect.

However, in order for performance measurement to be successful, the adaptation and implementation of it require involvement and commitment from all parties involved (Mossman, 2009; Sage et al., 2012). It is thus, as emphasized earlier, important to follow a structured and systematic approach throughout the process. This is in line with prior research that argues that without using appropriate performance measurement systems, it will become challenging for organizations to realize how to achieve improvement or why poor performance continues. Hence, it will be challenging to understand if the intended objective and goals will be achieved or not (Leong & Tilley, 2008; Neely et al., 1996). Both empirical findings and prior literature highlights the importance of reasonable and feasible methods and tools for measuring performance. Additionally, our findings emphasize that if the process entails too much hassle or is perceived as too challenging, it will not provide the necessary output for it to be value adding.

Our research also shows that one should not measure, just for the purpose of measuring, but rather to gain an understanding of how the measurements could be used to identifying areas for improvement. Furthermore, Behn (2003), along with the professor from NTNU, highlights the fact that it is only when the measurements are exploited that they will accomplish satisfactory results. We, therefore, find it reasonable to assume that there is a substantial potential of learning by analyzing previous data from other residential projects. Perhaps, increasing the transparency of the results could reduce the fear of measurements (Ashton et al., 1990; Bernstein, 2012). This is supported by our findings and empirical analysis where the documented results from previous measurements on Hagebyen allowed the project management team to make use of what they have learned and experienced to a greater extent into the next project, in this case, Frysjaparken. This further indicates that there is a possibility for knowledge sharing across the different projects in the organization. According to our data analysis, information is the highest ranked reason for deviation in both projects that have implemented performance measurement. Thus, this is something that could be applicable for several projects as this concerns the organizational work. We would also like to mention that it could be useful to calculate the “cost impact” associated with the different reasons for deviation when calculating TA, TMR, and PPC. This was, as mentioned, done at Hagebyen, and we believe that this could provide additional valuable information about the cost impact of the deviations. Thus, be able to address how the improvements might positively influence profitability.

Our interpretation of the purpose of performance measurements, based on previous literature and empirical findings, is related to the ability to identify areas for continuous improvement. The implementation of performance measurement systems demands, in addition to time and resources, reliable plans in order to increase performance (Ballard & Howell, 1994a; Liu et al., 2013). Lean thinking focuses more on workflow and plans reliability rather than finishing the project as fast as possible, and by focusing on flow efficiency, one can eliminate non-value activities, and thereby increase productivity (Chew, 1988; Rother & Shook, 2009). Performance measurements and VSM could, in that sense, suit useful to identify these activities and thereby increase plan reliability and increase productivity. The opportunity of combining VSM with plan reliability is in accordance to Lean thinking, as it emphasizes the opportunity to increase flow efficiency by working continuously with the plan and eliminate non-value adding activities (Rother & Shook, 2009; George, 2002; Ballard & Howell, 2004). Thus, by continuously updating the project plan and reducing non-value, adding activities could give satisfactory results and provide high project reliability. We, therefore, find it interesting to question the necessity of measuring performance, in addition, VSM and thorough project planning, since if this is done properly and according to the Lean principles, one will achieve satisfactory results.

In sum, our discussion addresses our first research question on how performance in Lean Construction should be measured, by arguing that it should be conducted in a systematic way, where each individual has more or less the same perception of how it should be used and the meaning behind it. Furthermore, when using the LPS metrics, we see that a systematic and consistent approach is necessary in order to implement and integrate performance measurements efficiently. Where the responsibility of this should be delegated to someone who can build trust and engage for commitment, this, or these, individuals should be capable of understanding the purpose behind the measurements. Moreover, both our empirical findings and prior research emphasize that it would be useful to develop a database for the exchange of experience based on the performance measurements. This is because knowledge and experience sharing is considered necessary in order to provide an overview of which aspects that has to be considered for improving flow efficiency.

To answer our second research question, on whether or not performance should be measured in Lean Construction projects, we have in this discussion addressed if it is according to Lean thinking. In order to be associated as a value-adding activity, the aim of doing this should be to help construction projects to focus on continuous improvements, trough identifying and eliminating waste. Initiatives which include working with VSM and ensuring in advance that activities are made ready for execution could perhaps be sufficient according to Lean thinking. In that sense, this would indicate that performance measurements would be excessive, and a non-value adding activity. Additionally, it is crucial to be aware that metrics such as PPC could be manipulated, meaning that the numbers would not sufficiently present a holistic and realistic overview. However, those who have successfully implemented and used performance measurement in their projects at Veidekke experience that they can identify potential areas for continuous improvement through measurements.

6.0 CONCLUSION

This chapter will present the conclusions and implications of our study based on our overall objective and two equally important research questions, followed by the limitations of our research and recommendations for future research.

6.1 Theoretical implications

In this study, we have sought to respond to our overall objective and research questions by investigating how performance measurements were implemented and adapted in Lean Construction projects, and whether or not it is perceived and conducted according to Lean thinking. Our research is based on a case study, allowing us to get an in-depth understanding of how and why performance measurement is used in the different projects studied. We have done so by directly observing and interviewing participants in six different construction projects at Veidekke, with special attention being paid to the practices of performance measurements. The empirical findings were then discussed and compared with findings from our theoretical background.

The first contribution of our research is that it provides much needed empirical data on both the practical and theoretical implications of how performance measurement should be conducted in Lean Construction. There are noticeable challenges and barriers to implementing tools for performance measurement due to the uniqueness and complexity of construction projects. The difficulty of collecting performance data on site and varying procedures for data collection in the different construction projects create challenges in developing measures for construction projects (Koskela, 1992). However, when performance measurements are used internally, these problems are possible to overcome. The data collection methods can be standardized internally when construction companies carry out comparable projects. Both our empirical findings and prior research demonstrates that if the goal is to acquire reliable performance measurement metrics and numbers that can be used purposefully in improvement work, a coherent and systematic framework for measuring performance must be developed (Fischer et al., 2017).

Additionally, as it takes time to learn new systems and concepts and to become skillful at using them, those who are responsible for planning and conducting the measurements should be properly trained and closely followed up (Aslesen &

Tommelein, 2016). A natural and necessary content in a framework for measuring performance is; a few key performance indicators (PPC, TA, and TMR) in addition to other selectable performance indicators, in combination with knowledge and competence about the measurements. This will provide those who are responsible for conducting the measurements a foundation that enables them to focus on continuous improvement, as well as a tool that helps them to collect and compare performance data over time. Accordingly, when managers (or the last planners) try to identify where the problems are, they need an approach to understand the different root-causes of the deviations. A much-emphasized method of identifying root-causes is asking the question "why" five times (Porwal et al., 2010; Sarkar, Mukhopadhyay & Ghosh, 2013). On each iteration, the Last Planner will dig deeper into the cause of deviation until the real reason is revealed. We believe that this also will reduce the variety in how the seven conditions for a healthy activity are interpreted, as this method allows for an in-depth analysis of the actual root causes.

The following figure (Figure 22) illustrates where in the project cycle the different performance measurement metrics takes place and highlights the importance of continuous evaluation and revision of the project plans in order to implement performance measurements in Lean Construction projects successfully. With this figure, we want to demonstrate our argument towards why performance measurement should be a part of the project strategy from the beginning of, and not randomly taken into use at any phase in the project.

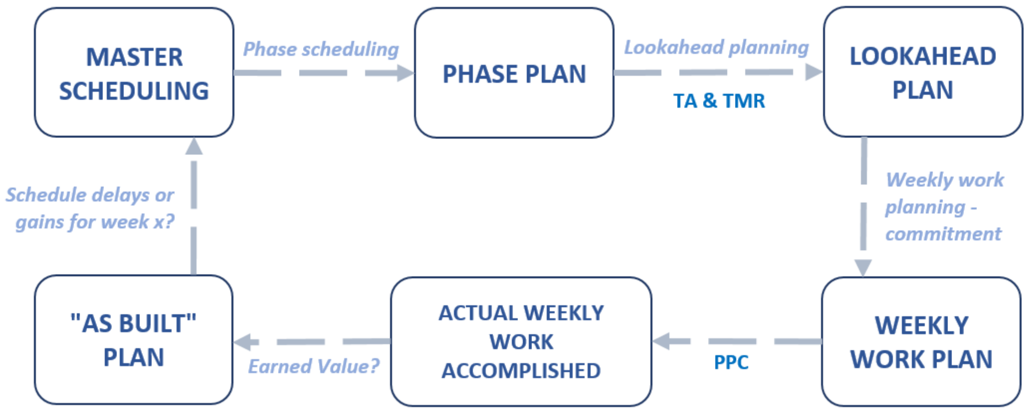


Figure 22: Planning cycle in the Last Planner System (adopted from Hamzeh, 2009)

There are several aspects that must be considered in order to achieve the potential beneficial effects of the measurements. Our literature study reveals that there seems to be a gap in prior research concerning the impact of knowledge and competence on performance measurement in Lean Construction. Moreover, our research contributes to enrichen the foundation of this literature, as our findings indicate that there is a lack of knowledge with respect to the purpose of the measurements and how they should be conducted. Accordingly, the variety of knowledge and competence influences the decision of whether or not performance measurements are included in a project, and how it is implemented and conducted by the project participants.

Our research identifies and points to a specific set of measures that needs to be in place in order to relate performance measurements with Lean thinking. Although PPC can provide valuable information, if used and analyzed properly, our research identifies some underlying challenges and implications. Due to the simplicity of the PPC metric, one is not able to capture important features such as for instance quality in the measurements as it only accounts for whether an activity is completed or not (Fosse & Ballard, 2016). Additionally, as our discussion illustrated (Figure 21), metrics such as PPC could be easy to manipulate. Therefore, our research emphasizes the importance of a well-established culture and suggest that, if found necessary, one could in advance evaluate each activity based on cost and risk in order to avoid manipulation of numbers. In addition to this, it is advised that metrics such as TA and TMR should be included, as it will positively influence the PPC. This is also in accordance to prior research (Hamzeh et al., 2015b). This was exemplified through our quantitative analysis, where the root-cause of several of the reasons for deviation was due to the lack of anticipated tasks (TA) and task made ready for execution (TMR).

A second important implication of our study derives from our findings concerning the informal conditions which affect performance measurements. From a theoretical perspective, our findings contribute both new and valuable knowledge and insight as they address how context (e.g., informal conditions) serves an important boundary condition of the relationship between performance measurements and Lean Construction. Our findings indicate that, in addition to the formal structures emphasized in how the measurements should be conducted, another important prerequisite for enhancing performance measurements is the cultural aspect. Our research accentuates the importance of personal commitment for those who are responsible for measuring performance, this is to ensure that the communication is precise, and that the metrics are used for the right purpose. Furthermore, it is also important to be aware that performance measurement in Lean Construction involves motivating everyone to improve past performance, not only the most capable or talented employees. Accordingly, our research suggests that a strategy for how the measurements are conducted and how they are communicated should be developed.

Additionally, our empirical findings revealed that the construction workers were missing feedback from their managers, both on their progress and on a general basis. Prior research emphasizes that timely feedback allows teams to produce higher quality, faster (Fischer et al., 2017). We, therefore, argue that in order to achieve the desired effects from performance measurement, practitioners must dedicate more attention to providing feedback to the different disciplines. The metrics should not be used to measure the quality of work performed by the different disciplines or each individual, and certainly not a metric used to expose or single out anyone (Fosse & Ballard, 2016; Powell, 2004). Instead, the metrics should be used as indicators to motivate for involvement and engagement, in work towards continuous improvement and flow-efficiency. In this sense, when conducting performance measurement in Lean Construction, our research, supported by theory (Leong & Tiley, 2008), emphasize the need for a culture that facilitates continuous improvement. As such, it should be based on a "performance climate" where trust, commitment, and clear and mutual communication serves as a basis for the measurements. This is important both when conducting performance measurements and working with the project plans (Aslesen & Tommelein, 2016). Moreover, if the cultural aspect and a common understanding of the measurements are in place, this will provide both the project team and the different disciplines greater motivation and higher self-efficacy. Prior research argues that this is positively correlated to greater work-related performance and job satisfaction, which is also supported by our empirical findings (Bandura, 1982, 2010; Stajkovic & Luthans, 1998; Ozyilmaz et al., 2018).

A third implication stems from the important question of whether Lean Construction projects should measure performance. Is it a value-adding activity and is it in accordance with Lean thinking. Our findings indicate that performance measurements could prove very useful for construction projects if it is implemented and commonly acknowledged by everyone involved (Aslesen & Tommelein, 2016). The underlying intention should be that the results are used to improve the overall productivity through identifying and eliminating waste, thereby, improve flow efficiency (Leong & Tiley, 2008; Modig & Åhlstrøm, 2018; Powell, 2004). It could, therefore, be necessary to measure performance in order to see the effect of the LPS implementations (Neely et al., 1996). However, performance measurement could be a time-consuming activity, especially when one does not have prior knowledge of it and have a concern towards learning new systems. Focused training should be offered in order to help the various participants to become more knowledgeable and comfortable, which is fundamental to the success of implementing systems for performance measurement (Aslesen & Tommelein, 2016).

Moreover, our research emphasizes the necessity of continuously updating the project plans in order for the measurements to be accurate and to avoid deviations (Aslesen & Tommelein, 2016; Ballard & Howell, 2004; Fisher et al., 2017; Hamzeh, 2009). Information was, as mentioned, one of the most frequent reasons for the deviation. We believe that by having a shared lookahead and weekly work plan, a construction project can avoid disciplines spending time and effort on locating, recreating and transferring fragmented information and in that way reduce deviations related to inadequate or inaccurate information (Aslesen & Tommelein, 2016; Fisher et al., 2017).

6.2 Practical implications for managers

Finally, our study provides some suggestions for managers that is based on some key considerations regarding several preconditions that need to be addressed when planning for or conducting performance measurement in Lean Construction.

In order to approach the question of whether or not performance measurement is according to Lean thinking, we find it reasonable to conclude that there is no final “yes or no” to this question. We have therefore developed a framework to raise awareness on the different dimensions of the phenomena addressed throughout our discussion. Such dimensions suggest that it is important to critically reflect on the following fundamental conditions and issues:

- *Why and how should we measure performance in our Lean construction projects? Moreover, what is the nature of our work at present?*

- *How is our culture, and do we have a culture that allows for measuring performance for continuous improvement?*
  - If not, then you have to be aware of how to overcome the challenges identified in this research.

- *Is there a commonly shared understanding of the purpose behind performance measurement? If so, how should the measurements be conducted, and how they should subsequently be used and communicated?*

- *Is there an infrastructure in place which allows to do this type of performance measurements (this includes people, IT systems and other resources)?*

These reflections are aimed at managers who work with Lean concepts in construction projects. However, we believe that these recommendations and this awareness is applicable and relevant to other managers as well. It is also important to mention that these dimensions should be addressed early in the project, in order to create a proper basis for measuring. Additionally, managers have to be aware of the impact of performance measurements on the work climate. Thus, we highlight the importance of proper communication and building trust in order to reduce the fear that might arise when being measured.

The framework, which is graphically summarized below (Figure 23), is premised on the notion that the question of whether performance measurement is in accordance with Lean thinking or not depends on some preconditions. The framework also suggests that there is no clear “one fits all”. However, it proposes that if the dimensions for “Yes” is most comparable for the given situation, then one can embrace performance measurements as in accordance with Lean thinking.

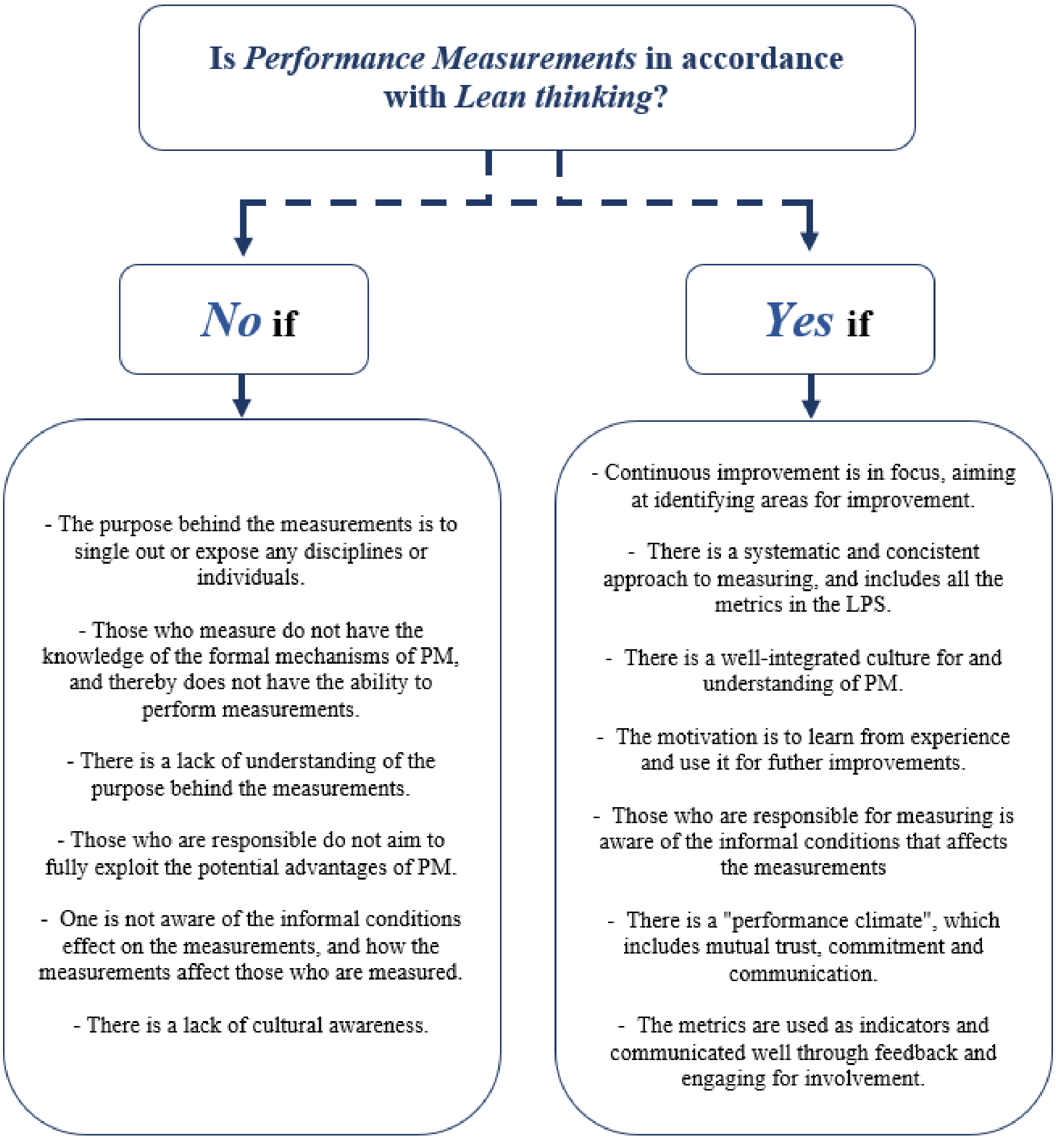


Figure 23: Is performance measurement in accordance with Lean thinking

6.2 Limitations and recommendations for future research

Our data collection was limited to how many projects we were able to visit and how many interviews we were able to conduct. Thus, we were not able to interview every actor, e.g., subcontractors, involved in the project. Although we believe that we gained a holistic overview of the research area, it could have been more complete if we were able to include more interviewees from other companies as well. However, the nature of a master thesis, based on time and resource limitations, restricted the research preventing us from generalizing our conclusions.

In sum, we believe that our restrictions could accentuate other interesting areas for future research. By conducting multiple case studies of how different Lean Construction projects measure performance, researchers would be able to generalize some of the findings. Additionally, quantitative research could capture if there is a positive or negative correlation between each LPS metric and thereby support our conclusions. Furthermore, our study does not evaluate and explore all of the different performance metrics in the construction industry, nor the different systems that exist. We have briefly discussed the Average Labor Productivity (ALP), which we believe should have been further investigated and discussed upon, given the characteristics of the construction industry especially with the trends in automatization and prefabrication. Additionally, there is a new project coordination tool called *CII 10-10* (Oshikoji & Andersen, 2017), which are being implemented by some companies in Norway. We believe that it could be interesting to further investigate this system in light of the findings from our research.

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APPENDICES

Appendix 1: The roots of Lean Philosophy

The philosophy of Lean has its roots from the early 1900s with the revolution of the automotive industry, where Alfred Sloan and Henry Ford were the innovators of the revolutionary philosophy (Womack, Jones & Roos, 2007). The revolution consisted of what we know today as the assembly line technology and allowed mass production on a completely different level. By introducing machines that performed a particular type of task, they managed to reduce their skilled labor requirements. Combined with a rigid program for their workers, they also managed to decrease the need for training their employees. Furthermore, when implementing the assembly line in the production process, they were able to reduce the transport time of semi-finished car components. This created economies of scale in the manufacturing facility and reduced unit costs, which resulted in a substantially lower sales price of the vehicles. However, Womack et al. (2007) emphasize how the assembly line resulted in simple and repetitive work tasks that demanded less knowledge from the workforce.

The production method was further developed by Toyota Motor Corporation with Taiichi Ohno, Shigeo Shingo, and Eiji Toyoda. They studied the production method previously used in the United States of America and criticized some of the methods used (Toyota Global, 2016). They believed that the resources did not get optimally utilized and that it would be difficult to adapt the production to the volatile demand. In addition, they pointed out that mass production, with the lack of flexibility in working methods, resulted in inferior quality with several faulty components, and thereby lowered the quality of the final product. Based on their studies, they developed a system called the Toyota Production System (TPS). This system directed the focus towards other aspects of the production process, particularly waste and quality. They argued that simple changes and innovations in processes could offer a broader product portfolio to the customer while maintaining an efficient production flow (Morgan & Liker, 2006). The changes included a shift in the focus from the individual processes and machines to the way the flow in the total value-chain was designed. The overall goal was to ensure that all the activities in the value chain would increase the experienced customer-value.

James P. Womack with colleagues created in 1997 a "Lean Institute" with an intention to further develop the TPS concept (Lean Enterprise Institute, n.d). They stated that the production processes which took place in the automotive industry were similar to the ones at Ford's assembly-line production and thus outdated; “They were simply not competitive when it came to the future modern requirements” (Womack et al., 1990, p.3). They performed a comparative analysis and mapped the differences between traditional mass production and Lean production, which was deliberately practiced among others in Toyota. The result was significant, where they immediately found major differences between the two methods. It was observed that the assembly line went in “jerks” in the factory halls that practiced traditional mass production. Due to this, the workload was not even weighted between the groups, which resulted in that some were overloaded, and others capacity were not utilized. At the end of the assembly line, there was much rework when the quality was not in accordance with the given standard (Womack et al., 2007).

By focusing on the challenges of traditional mass-production, they managed to improve the productivity and quality in the American auto-manufacturing industry. Gradually, other nations learned from the Americans and adopted their mass-production system. Thus, the machine- and eventually, robotic-technology became relatively similar across the world. Consequently, the Americans lost their competitive advantage, and a lack of innovation and new thinking became a distinct challenge (Kale, 2014). In 1988 Jack Krafcik launched the term “Lean” in the journal Sloan Management Review, with the purpose of being a collective term for what the concept was all about. Krafcik was destined to describe why the Japanese automakers, in particular, Toyota, had greater success than their competitors.

Appendix 2: The Interview Guide

Fortell litt om deg selv og din bakgrunn hos Veidekke? Hva tenker du om byggebransjen?
Hvilke erfaringer har du med Lean Construction, eks. involverende planlegging? • Bare hos Veidekke?
Hvilke aspekter syns du er viktig innenfor involverende planlegging?
Det hadde vært litt interessant å høre mer om din rolle innenfor involverende planlegging, og hvordan du tilpasser din arbeidsdag til metodikken?
Hva er din erfaring og holdning til prestasjon/produktivitetsmålinger? Hva tenker du er hensikten med målinger?
Hvis ja: Hvordan var måleprosessen lagt opp? Og hvordan ble resultatene/dataen brukt?
Hva mener du er viktig når man skal måle prestasjoner/produktivitet? Og hva tenker du er kritisk i denne prosessen?
Hvordan avdekker man aktiviteter som ikke blir målt, og effekten av disse på målingene? Vet du noe om hvordan resultatene blir brukt ut mot prosjektet? Får dere/gir dere informasjon om de forskjellige fagene ligger an?
Hva opplever du er utfordrende med målingene og er det noe du ville gjort annerledes? Hva funker her som ikke finner andre steder
Hvordan/hvilke målinger kan brukes på prosjektet?
Viktigste argument for å ikke gjøre målinger, hva bruker man heller tiden på? eller hva er viktigere å prioritere
Har dere noen gang gjort samme feilen flere ganger og hvordan har arbeidet rundt det vært?
Tilleggsspørsmål
Kunne man brukt dagtid som et mål på unødvendige aktiviteter/uforutsigbare?
Hvordan føler de ansatte føler å bli målt på aktivitet?
Hvordan gjør dere tiltak for de ulike aktivitetene?

Appendix 3: Measuring productivity in Veidekke

Frysjaparken

Plan	Fag	Antall aktiviteter	Antall planlagt utført	Utførte	PPU	Kommentar	Forutgående	Informasjon	Materialer	Mannskap	Utstyr	Plass	Ytre forhold
Uke 48	Betong	48	47	40	85.1 %	1) Armering dekke tun ikke startet som planlagt. Dekkereisen tar mer tid enn planlagt. 2) Innervegger under del B blir ikke helt som planlagt. Rekker 4 av 6 vegger. 3) Yttervegg D3-1 tok lenger tid enn planlagt, er lagt mer fokus på kjeller slik at denne planen følges.4) Mye kranbruk med to fronter gjør at man ikke rekker det som er lagt inn i plan. Derfor blir det mer fokus på kranbruk fremover. Utfordringene ligger nå på hus 3, og hus 2 er snart ferdigstilt til råygg.		3		2	2		
Uke 48	Tømmer	10	4	3	75.0 %	1) Oppstart isolering bindinsgverk utsatt 1 uke for å få kontroll på fuktsikring. Ramirent har ikke levert inndekking som avtalt her, og det er varslet kostnader som følge av utsettelsen.		1					
Uke 49	Betong	20	19	16	84.2 %	1) Yttervegg er prioritert ned inntil søyler og vegg som kan sette i gang bygging av drager kan begynne. 2,3) samtidighet på kjellerdrift og etasjedrift krever mye kran og vi ser oss nødt til å prioritere kjeller for å få komplett syklus i neste etasje. Vi opplever også mye sykdom denne uken, og 3 av 12 mann er borte. Det merkes på driften.		1		1	1		
Uke 49	Tømmer	7	4	4	100.0 %	Bra fokus denne uken på drift. Følger planen både innvendig og på fasade.							
Uke 50	Betong	20			#DIV/0!								
Uke 2	Betong	24	22	16	72.7 %	D.O kjeller på B og A trekker ned, og ligger bak planen. Ellers aktiviteter ok.	2	3			1		
Uke 2	Rør	6	6	5	83.3 %	Forutgående plattendekke ikke lagt.	1						
Uke 3	Betong	21	19	16	84.2 %	Støp dekke del A over kjeller. Ligger feil i planen. Kortvegg i søppelrom nedprioritert grunnet tun haster mer.		2					
Uke 3	Rør	4	3	3	100.0 %								
Uke 3	EL	3	2	2	100.0 %								
Uke 3	Tømmer	7	4	4	100.0 %								
Uke 4	Betong	19	16	11	68.8 %	Montering trapper tar lenger tid grunnet feil høyde på utsparinger. Skallvegger og dekkereis kunne ikke gjøres feridg grunne forinket trappemontering. Støp dekke del C utsatt en dag, mer jobb med nedsenk enn antatt. Veggfyring fungerte ikke som det skulle, tapte en veggproduskjonsdag.	3			1	1		
Uke 4	Rør	3	3	3	100.0 %								
Uke 4	EL	3	3	3	100.0 %								
Uke 4	Tømmer	10	5	5	100.0 %								
Uke 5	Betong	19	16	13	81.3 %	1 og 2) rakk ikke montering av skallvegger og dekkereis på del A 9 etg grunnet lang monteringstid på trapper. Skyldtes utførelsesfeil i forbindelse med utsparinger til trappene. 3) støp dekke del C ble ikke hus 3 ble støpt 1 dag senere, tok lenger tid med dekkesteng.	2						1
Uke 5	Leca	4	2	2	100.0 %								
Uke 5	Stillas	2	2	1	50.0 %	Var avhnegig av fasade 5 ferdig før fasade 4 kunne rives grunnet adkomster.	1						
Uke 5	Blikk	4	3	2	66.7 %	Fasade 5 tok litt lenger tid og prioriterte fasade 6 for å gjøre klrt for oppstart puss på fasade 7.				1			
Uke 5	Mur	1	1	1	100.0 %								
Uke 5	Tømmer	10	6	5	83.3 %	Vindtetting ikke startet grunnet manglende stillas rundt bygget. Er på gang.					1		
Uke 5	Rør	3	3	3	100.0 %								
Uke 5	EL	3	3	3	100.0 %								
Uke 5	Tekking	2	1	1	100.0 %								
Uke 6	Betong	32	29	10	34.5 %	Mye forskyvninger denne uken. Skyldes både mye sykdom i laget og mye nedbør i form av snø. 38 % fravær er registrert for uken. Både utfordringer med snømåking og fyring til dekke er medvirkende årsaker til den lave treffprosenten.				10			9
Uke 6	Tømmer	10	5	4	80.0 %	Endring i fremdrift. Foran plan totalt . Gjelder vindtetting.		1					
Uke 6	Fug	1	1	0	0.0 %	Har ikke folk på plassen. Kapasitet.				1			
Uke 6	Stillas	4	1	1	100.0 %								
Uke 6	tekking	3	2	1	50.0 %	Mye nedbør uke 6. Brukt mye tid på snømåking							1
Uke 6	Heis	2	2	0	0.0 %	Mannskap fra Otis var syke. Utsatt 1 uke. Ikke på kritisk linje.				2			
Uke 6	Blikk	3	3	3	100.0 %								
Uke 6	Brannisolering	2	2	2	100.0 %								
Uke 7	Betong	23	19	15	78.9 %	1) dekkeproduksjonene på del A utsatte felt E -1 dag grunnet feil på pl.dekke 2,3,4,5) Vegger på del C tar noe lenger tid enn planlagt. Sliter med 2 vegger per dag som er lagt i planen.	2	1	1				

Gartnerkvartalet

Gartnerkvartalet

Bindingsverk	Fasade	Tømmer 1	Teknisk 1	Tømmer 2	Teknisk 2	Tømmer 3		Teknisk 3			Tømmer 4	Teknisk 4
Bindingsverk og duk	Vinduer	Del 1	Rør/bokser i YV. 2 dager	Stål lettvegger	Ferdigtrukne rør i lettvegg	Isolering av innervegg	Sparkling. 2 dager	Komplettering av el i leiligheter inkl stikk vent	Parkett. 5 dager	Kjøkken. 5 dager	Dører	Komplettering kjøkkenhetter og -ventiler. 4 dager
	Spikerslag til solskjerming	10+10 cm. Isolasjon. 2 dager	Radiator ut av påforing + sprinkel i badekabin. 1 dag	Spikerslag kjøkken	Montere sikringsskap. 4-5 dager	Lukking av vegger. Totalt 5 dager	Maling. 11 dager	Innmat sikringsskap	Vann og avløp kjøkken. 2 dager	Gulvbelegg korridorer - trapp + Gulvbelegg toalettrom. 2 dager	Utforing vindu	Koble kjøkken, RØR. 1,5 dager
	Blikkenslager: Beslag rundt vindu	Plast og utlekting 5 cm. 3 dager	Stammer i sjakt (spv, vann) Koble vann og avløp badekabin Isolering KV + VV + sirk + takvann. 1 dag pr sjakt pr etg	Enkling en side	Avløp kjøkken + Vann kjøkken. 1 dag	Horrisontalt strekk ventilasjon kasser/himling + Horisontalt strekk ventilasjon over kjøkken. 4 dager		Porttelefon		Montere rastere i fellesarealer . 2 dager	Listverk	Lys kjøkkenskap. 1 dag
	Lekter	Justering kabiner. 1 dag	Isolering av sjakter. 4 dager	Totalt 4 dager	Isolere rør i sjakter. 5 dager	Lys i himling. 1 dag		Koble styremotor. Totalt 4-5 dager			Luker og sluttkontroll. Totalt 7 dager	Sluttkontroll EL påsetting strøm. 2 dager
	Puss pl./panel	Ventilasjon ut av badekabin. 2 dager	Vertikalt strekk i sjakter, til like over dekke avstand iht. branntetting. 2 dager		Wc-rom. 1 dag	Sprinkelhoder. 2 dager						Utestikk+lampe, etter beising. 1 dag
	Beising av panel	Del 2 (Med tek 1)	Branntetting av sjakter ventilasjon. 2 dager		Trekke PEX og feste i tak (fra kabiner)	Kasser/ himling. 3 dager						Montere utstyr WC-rom. 1 dag
	Montering tremmer	5 cm isolasjon			Branntetting sjakter. 2 dager							Montere radiator. 3 dager
		Gips yttervegg. 3 dager			Merking av hull hull i leil. 1 dag							Funksjonstest rør. 1 dag
												Lås og beslag

Hagebyen

Uke	Totalt	Planlagt	Utført	PPU	Forutgående	Informasjon	Materialer	Mannskap	Utstyr	Plass	Ytre forhold	Bemanning	Per aktivitet
10		2	2	100.0 %	0	0	0	0	0	0	0		
11		7	5	71.4 %	0	0	1	1	0	0	0		
12		9	8	88.9 %	0	0	0	1	1	0	0		
13		8	6	75.0 %	0	0	0	0	2	0	0		
15		9	6	66.7 %	1	0	1	0	0	1	0		
16		8	6	75.0 %	1	0	0	0	0	1	0		
17		9	8	88.9 %	1	1	0	0	0	0	0		
18		2	2	100.0 %	0	0	0	0	0	0	0		
19		15	13	86.7 %	1	1	0	0	0	1	0		
20		4	3	75.0 %	0	0	0	0	1	0	0		
21		11	9	81.8 %	0	0	1	1	0	0	0		
22		15	12	80.0 %	1	1	1	1	0	0	0		
23	33	21	20	95.2 %	0	0	0	0	0	1	0	31	1.065
24	28	25	21	84.0 %	1	1	0	2	0	0	0	31	0.903
25	31	24	20	83.3 %	0	4	0	0	0	0	0	31	1.000
26	35	28	27	96.4 %	0	0	1	0	0	0	0	32	1.094
27	27	26	27	103.8 %	0	0	0	0	0	0	0	32	0.844
31	44	32	30	93.8 %	0	2	0	0	0	0	0	38	1.158
32	36	27	24	88.9 %	0	2	0	1	0	0	0	55	0.655
33	52	43	38	88.4 %	2	5	0	1	0	0	0	62	0.839
34	57	47	41	87.2 %	0	5	0	1	0	0	2	65	0.877
35	54	43	40	93.0 %	0	0	0	1	0	1	1	65	0.831
36	67	55	52	94.5 %	0	3	0	0	0	0	0	68	0.985
37	68	47	38	80.9 %	4	4	0	0	1	0	0	68	1.000
38	72	52	44	84.6 %	2	1	3	2	0	0	0	68	1.059
39	62	50	42	84.0 %	0	3	0	3	0	0	2	72	0.861
40	27	15	13	86.7 %	0	0	0	1	0	0	0	52	0.519
41	57	35	31	88.6 %	0	3	1	0	0	0	0	82	0.695
42	52	45	43	95.6 %	0	1	0	0	0	0	1	81	0.642
43	36	23	19	82.6 %	4	1	0	0	0	0	0	66	0.545
44	60	45	37	82.2 %	3	5	0	0	0	0	0	61	0.984
45	57	37	34	91.9 %	1	2	0	0	0	1	0	63	0.905
46	59	40	39	97.5 %	0	0	1	0	0	0	0	68	0.868
47	66	43	43	100.0 %	0	0	0	0	0	0	0	64	1.031
48	66	42	36	85.7 %	2	2	2	1	0	0	0	58	1.138
49	50	28	27	96.4 %	0	1	0	1	0	0	0	53	0.943
50	52	34	25	73.5 %	0	4	2	3	0	0	0	47	1.106
51	40	23	17	73.9 %	1	1	0	4	0	0	0	40	1.000
1	51	14	9	64.3 %	1	2	0	0	0	0	0	34	1.500
2	75	41	32	78.0 %	2	2	0	5	0	0	0	59	1.271
3	56	34	23	67.6 %	1	7	0	2	0	0	0	75	0.747
4	69	38	29	76.3 %	2	3	0	5	0	0	0	67	1.030
5	81	55	45	81.8 %	0	4	0	6	0	0	0	68	1.191
6	78	49	42	85.7 %	0	5	0	2	0	0	0	74	1.054
7	87	50	44	88.0 %	1	3	0	0	2	0	0	64	1.359
8	78	39	35	89.7 %	0	3	1	0	0	0	0	62	1.258
9	81	43	40	93.0 %	1	1	0	1	0	0	0	59	1.373
Uke 10	85	49	43	87.8 %	2	3	1	0	0	0	0	53	1.604
Uke 11	87	62	49	79.0 %	1	9	1	2	0	0	0	59	1.475
Uke 12	55	32	29	90.6 %	0	0	2	1	0	0	0	53	1.038
Uke 14	59	24	16	66.7 %	2	6	0	0	0	0	0	47	1.255
Uke 15	84	43	35	81.4 %	3	3	0	0	0	2	0	45	1.867
Uke 16	93	32	28	87.5 %	2	0	0	1	0	1	0	58	1.603
Uke 17	105	59	43	72.9 %	1	8	0	7	0	0	0	60	1.750
Uke 18	84	45	41	91.1 %	1	2	0	3	0	0	0	59	1.424
Uke 19	68	46	37	80.4 %	5	2	2	3	0	0	0	63	1.079
Uke 20	76	43	34	79.1 %	7	2	0	0	0	0	0	63	1.206

Appendix 4: Projects at Veidekke

Sølvparken in Kongsberg

Veidekke Entreprenør AS signed in 2017 an agreement with Sølvknuten AS at Stor-Oslo Eiendom AS considering the construction project Sølvparken. This contract is a turnkey contract of 348 million excluding VAT. Sølvparken will consist of 68 apartments, commercial property and garage facilities in the city center of Kongsberg. This project is intended to be a fully CPM project and was for that reason chosen to be a part of this research. The management has much experience working with Lean Construction and in particular with CPM and are convinced that the methodology truly streamlines and improves their work performance. Our research took place at the very beginning of the project phase, where concrete work was carried out to lay the foundation for the buildings and the surrounding areas. At this point, the project manager and his management team were just about to start planning how they wanted to facilitate CPM, performance measurement, and meeting activities. It came clear during observations and interviews that they at this stage had not agreed on a specific method or plan of how to handle this.

Frysjaparken in Oslo

Veidekke Entreprenør AS also signed an agreement to build the first step of Frysjaparken in Oslo, consisting of 154 apartments divided into three apartment blocks. Frysjaparken is owned by OBOS Nye Hjem AS and Stor-Oslo Eiendom amongst others. Stor-Oslo Eiendom has been responsible for project management and development of Frysjaparken, which upon completion will consist of over 900 apartments in addition to some commercial property. A contract is a turnkey contract with a contract value of NOK 413 million, excluding VAT. Morten Barreth is a department manager and project portfolio manager at Veidekke and was at the beginning project manager for Frysjaparken. He is well known for his work with CPM and performance measurements in Veidekke and has been working a lot with development and performance measurement since he started. The management team at this project has been working with Barreth since they graduated and started in Veidekke as trainees. Both the project manager and the construction manager are very fond of the practices of performance measurement, which Barreth has taught them and have developed their own method and system for measuring PPC. Frysjaparken will be finished in the last quarter of 2019, and therefore provided us with good information and data related to performance measurement.

Nyegaardskvartalet in Oslo

Nyegaardskvartalet started in 2018 by Veidekke Bolig and holds for 250 residential apartments and a couple of company premises at the end of the project. These will be divided into three main buildings, and they are now building the first one. The project is predicted to be finished by 2021 and will also be one of the first and largest fossil-free construction projects in Norway. Nyegaardskvartalet is in the same project phase as Frysjaparken. However, they have up until now not carried out any specific calculations. This project was found interesting to compare.

Ulvenparken in Oslo

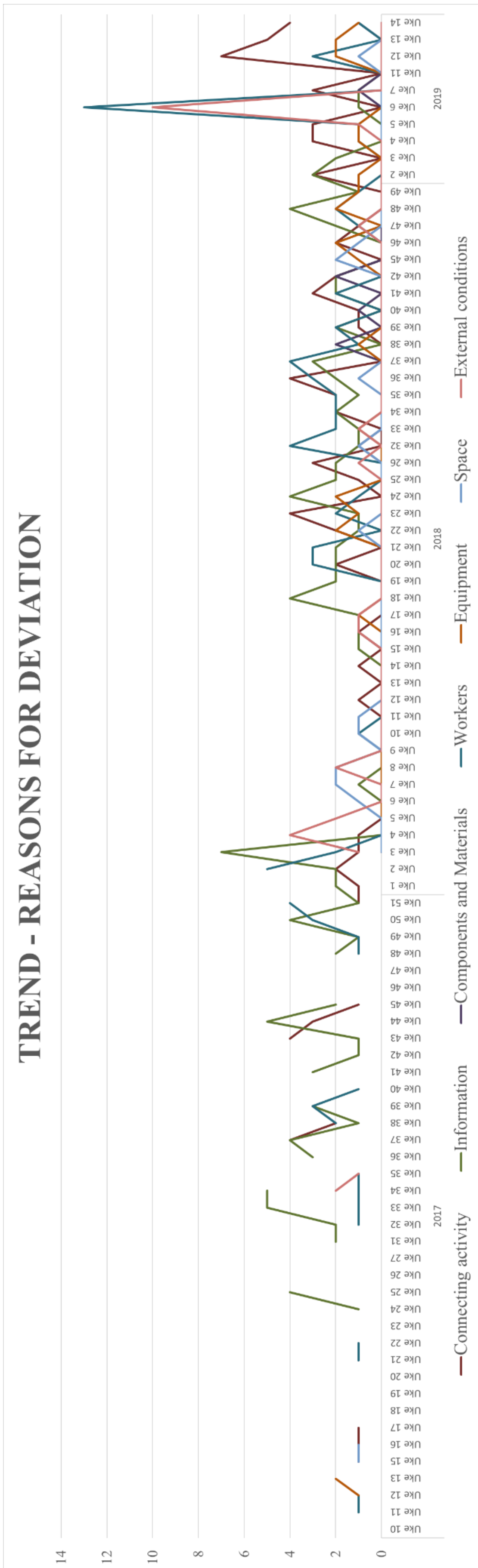
Ulvenparken is one of OBOS's largest-ever development projects and will be collaborating with Veidekke transform the 28-hectare site at Ulven in Oslo into several residential buildings consisting of over 2,000 apartments. The construction start-up was in December 2018; while the first occupants are due to take over their new apartments in the autumn of 2021. Ulvenparken is almost in the same phase as Sølvparken and was included to get an overview of how performance measurement is considered at the beginning of the project.

Hagebyen in Bærum

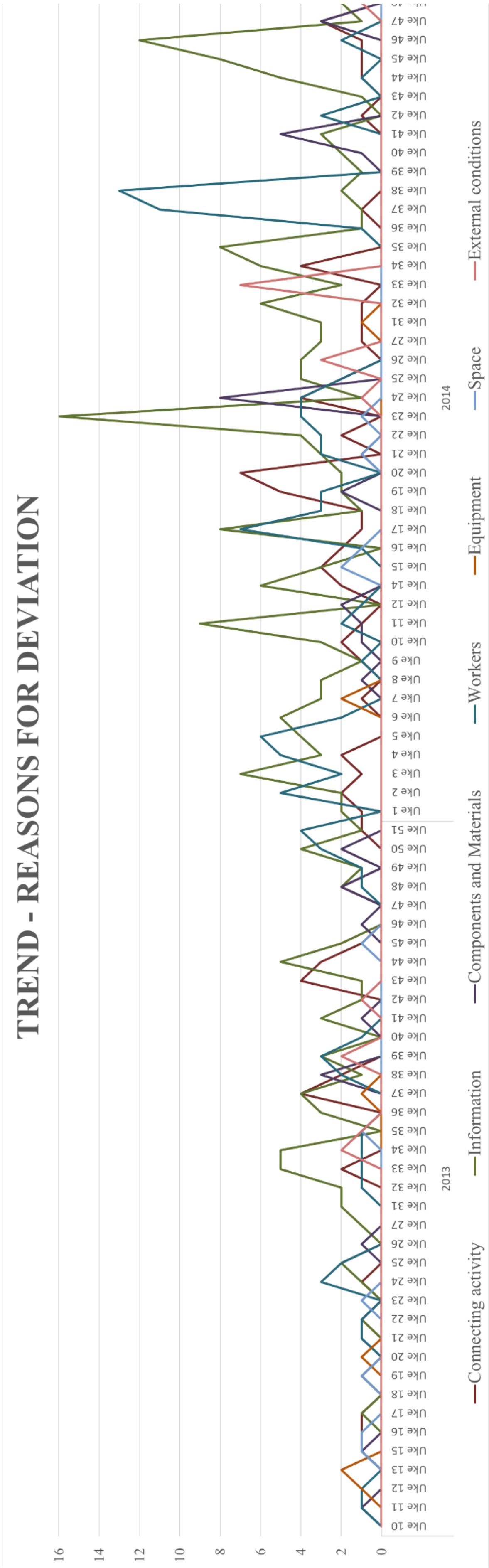
Veidekke Entreprenør AS was responsible for the construction of Hagebyen which consisted of 345 residential houses at Fornebulandet in Bærum. Veifor is owned 50-50 by Fornebu Utvikling and Veidekke Eiendom. Hagebyen was divided into four phases which started in 2012 and was finished in 2014. This project was chosen to be included due to the thorough documentation of calculations that were carried out in the project. This will provide us with a basis for comparison to the results we get from Frysjaparken.

Appendix 5: Trend in reasons for deviations

Frysjaparken



Hagebyen


TREND - REASONS FOR DEVIATION
2013
2014
Connecting activity
Information
Components and Materials
Workers
Equipment
Space
External conditions