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Measuring Lean Construction

A Performance Measurement model supporting the implementation of Lean practices in the Norwegian construction industry

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Abstract

The thesis examines the current performance improvement attempts in the construction industry and how their effects could be measured to sustain their implementation. The practices utilized in the industry under Lean Construction principles are the Last Planner, Pull Scheduling, Concurrent Engineering and Virtual Design Construction (VDC).

Construction companies in Norway have been implementing a number of practices intended for improving performance during the last decade. Although they have achieved relative success and perceived some benefits, companies find difficult to assess to what extent the benefits obtained are the consequence of implementing these practices. In addition, companies have recently shown interest in performance measurement systems as the way to know how is the actual performance of projects. The literature review shows a trend in the development of performance measurement towards industry- and purpose-specific frameworks. Other generic frameworks like the Balanced Scorecard, the EFQM Excellence Model, KPIs and Lean Six-Sigma have been reviewed during the study.

By using qualitative research the thesis aims to identify the practices implemented and measure their effects on project performance. It considers a stakeholder analysis perspective and the success factors in the implementation. The result is a performance measurement model supporting the implementation of Lean Construction. The model also establish the relationship between the practices used and the expected effects, and purposes an evaluation worksheet to facilitate the internal benchmarking of projects. The logic of these three elements together is described in the implementation roadmap.

The originality of the work is bringing together performance measurement and Lean Construction, the stakeholders' perspective on the needs for the implementation of Lean practices and the explicit inclusion of external factors in the project evaluation. However, there are also some limitations about the data collection as the lack of measurement culture and project metrics being collected, and the interrelation among the effects observed, which could be studied in the future. Further research also include the further application of aggregation methods for the indicators included in the evaluation.

Keywords: Lean Construction, Performance Measurement, Effects, Project evaluation

To my parents, Arsenio and María Jesús for their unconditional support

To my family and friends, for feeling so close though living so far

To Idun, for sharing and enriching my life

To all the people in Trondheim that have made me feel warm and welcomed

Table of Contents

List of Figures

List of Tables

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Chapter 1:

Introduction

This chapter presents the framework of the study that represents the pathway of the thesis and delimits the scope of the work establishing the fundamental boundaries. It starts with a basic theoretical background and follows presenting the research objectives and scope. It also introduces the topics that are further developed along the thesis by answering questions about the relevance of measuring performance. Finally, it provides an overview of the thesis' structure.

The elaboration of this thesis is part of the research project SpeedUp at Sintef, a Prosjekt Norge initiative. Several organizations from both the industry and the academia participate in the project. The main objective is to develop strategic, tactical and operational measures in order to reduce overall execution time in complex construction projects by 30-50%. The thesis focuses on the contribution of Lean to this goal and the performance measurement systems as tools supporting its implementation.

Background

After two decades from the first concepts of a new philosophy related to Lean applied in the construction industry, there have been a clear progress in its implementation. The development of the Lean Construction literature has been significant and practitioners

have shown increasing interest in new methodologies. The change of paradigm announced by Koskela (1992) continue taking place nowadays.

Since Lean practices arose in the manufacturing industry, its implementation in the construction industry has not been straightforward and has required a long process to adapt Lean to the distinguishing characteristics of the construction business: the one-of-a-kind type of project, site production and temporary creation of multi-organization (Koskela, 1997). Some of these practices at the origin of Lean Construction are the Last Planner System, Pull Scheduling and Just-in-Time delivery (G. Ballard & Howell, 2003). Other practices, such as Concurrent Engineering were developed in parallel to Lean although they are often found integrated under Lean principles (Koskela, 1997). More recently, Concurrent Engineering together with other practices such as Virtual Design Construction and Set Based Design contribute to extend Lean practices over the project life cycle (G. Ballard, 2008).

Once covered the difficulty of creating specific practices in order to apply Lean principles in the project-based construction industry (Powell, Strandhagen, Tommelein, Ballard, & Rossi, 2014), the challenge was to drive the organizational change towards the new methodologies. Organizational culture factors in construction needed to be addressed for a successful implementation of practices (Cheung, Wong, & Wu, 2011). From the experience implementing Lean in manufacturing industries, it was already realized the challenges in the implementation process (Dombrowski & Mielke, 2014). The establishment of a performance evaluation system is among the critical success factors for implementing Lean in manufacturing industries (Bakås, Govaert, & Van Landeghem, 2011).

The idea of applying performance evaluation systems on Lean implementation can be extended to project-based industries without having added negative effects (H. A. Bassioni, Price, & Hassan, 2005). However, even though these systems have proved to help driving change, they also account for implementation barriers that should be considered together with the Lean-specific factors. In addition, the study of success factor in construction projects can also contribute to the development of an effective evaluation system. All these elements creating the boundaries of the thesis are exposed in Figure 1 showing the framework of this study.

Research objectives

The key objective of this thesis is to study of performance improvement practices in the construction industry and how performance measurements systems could be used to support the successful implementation of these practices. This objective is described in greater detail through the four research questions identified. The first question aims to find the current practices used by organizations to improve their performance, whereas the second question focuses on the effects of these practices. The third question address the implementation challenges from a stakeholder perspective by trying to identify their needs. The last and main question of the thesis is how the mentioned effects can be measured. These questions guide the research from the current status of Lean practices and stakeholders' needs towards the methods for measuring the effects realized over the first steps of the implementation. Following are the research questions, although further details are presented in Chapter 5.

1. What performance improvement attempts are construction companies carrying on?

2. What are the effects of these practices in project performance?

3. What are the stakeholders' needs in the implementation process?

4. How can these effects be measured (in order to support the fully implementation of those practices)?

Given the recent interest of the targeted industry in performance measurement, it was not possible to obtain direct data from organizations and therefore the data collection required different sources for the issues involved. On one side, qualitative research is used to describe current practices in Lean Construction. On the other, extensive literature review on performance measurement supports the exploratory research for creating a purpose-specific measurement model, including the description of the most relevant generic frameworks and the presentation of other derived frameworks designed for specific purposes.

Research scope

The scope of the thesis is graphically described in Figure 1. The basic boundaries are defined by the construction industry in Norway. On one hand, the frequent presence of programmes for the implementation of Lean practices within Norwegian construction companies allows settling the focus on the segment of the organizations using these practices. On the other hand, the lack of measurement culture within construction projects makes appropriate to take the perspective of measurement systems as tools for improving the implementation of Lean practices. Furthermore, the figure recognizes the presence of both concepts further the construction industry.

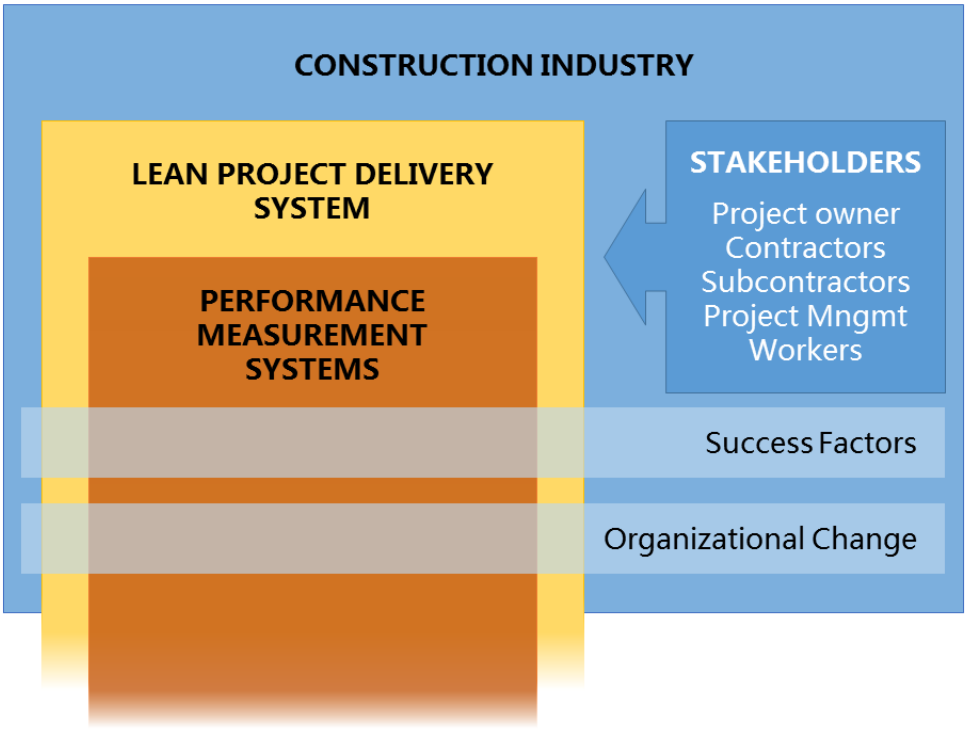

Figure 1: Study framework of the thesis

When bringing the mentioned concepts together there are also other issues that are necessary to address. Firstly, the implementation of new methodologies necessarily involve a certain degree of organizational change that needs to be managed, such as resistance to change, adaptation of work methods, using new systems, learning process and not less important the adoption of a new culture within the industry. Secondly, there has been a continuous search of success factors in construction projects that are wise to be considered, as well as success factors in the implementation of Lean and Performance

Measurement systems. For this reason, both organizational change and success factors appear as horizontal elements.

Finally, construction projects involve a significant number of stakeholders with different and often contradictory interests. Consequently, a thorough stakeholders' analysis is necessary to acknowledge and understand their specific needs and expectations in the implementation process of new methodologies. The successful implementation of the practices considered requires the involvement of the different actors and hierarchy levels of the project.

The scope of the thesis is limited to primary effects realized during the implementation process of Lean practices, which excludes aspects like political issues, organizational governance, portfolio selection or adoption of new technology. Although implementation issues are reviewed, a detailed step-by-step guide for the actual implementation of the model is out of the scope of the thesis. For example, reporting methods and explicit review procedures are not specified as part of the model. With the contemplation of all the elements included in the study framework, the reader is ready to initiate the journey throughout this thesis.

Why do organizations measure?

Performance Measurements Systems are often used as a strategy implementation tool (Niven, 2002) or should at least be connected to the strategy to drive change towards success (Johnson, 2002). On the other hand, managers measure for two basic reasons included in the mentioned strategic control: to identify areas for improvement and to influence people's behaviour (Beatham, Anumba, Thorpe, & Hedges, 2004; Robinson, Anumba, Carrillo, & Al-Ghassani, 2005). Using a performance evaluation system, independently of the core purpose, will affect actions and decisions (J. Hauser & Katz, 1998). In words of A. Neely, Adam, and Kennerley (2002, p. 9), '*measures send people messages about what matters and how they should behave'.*

In construction organizations, the use of performance measurement systems is aligned with strategic control purposes (Bassioni et al., 2004c). More specifically, excellence models have been used to provide an overview of the business performance. On the other

hand, the Balanced Scorecard is used in the strategic management to evaluate such objectives. Construction companies need both type of performance assessment to measure strategic performance while knowing where they have to improve and guide employees' behaviour (H. A. Bassioni et al., 2005).

Melnyk, Bititci, Platts, Tobias, and Andersen (2014) discussed the role of performance measurement and management systems. The claimed that the foremost cause of failure in the use of these systems is that measures and metrics were not being revised or they were incorrectly revised periodically although they were used in turbulent environments. In dynamic environments, co-creation of strategy and performance measurement would produce a more resilient system. Bourne, Mills, Wilcox, Neely, and Platts (2000) also concluded the need of specific processes to continuously align the performance measurement system with the strategy.

Why the need of new ways of Performance Measurement?

Financial measures are present in every business and they have been the centre of management practices for decades. Even today it is not difficult to find examples of companies relying almost solely on financial results (Andersen, Olsson, Onsøyen, & Spjelkavik, 2011). Financial measures have been criticized from the origins of the creation of new evaluation methods because of their lack of strategic focus and responsiveness in contemporary business realities, encourage local optimization and short-term results, giving information only about past performance and they fail promoting continuous improvement (Kagioglou, Cooper, & Aouad, 2001). New performance measurement systems need to be effective measuring performance, consider the increasingly important intangible assets and overcome the implementation challenges (Niven, 2002).

The appearance of generic models of performance measurement intended to overcome the mentioned dysfunctionalities of financial-based measurement systems as mentioned previously with the use of excellence models and balance scorecard. However, Andy Neely, Gregory, and Platts (2005) revealed the need of adaptation of performance measurement frameworks to the construction industry. The foundation for this statement

is that every measurement system requires adaptation when they are implemented within the organization, questioning the actual existence of 'generic' frameworks (Andy Neely et al., 2005). Several authors have developed, often based in these generic frameworks, performance measurement models to deal with specific needs depending on the phase of the project (Kristensen, Andersen, & Torp, 2013) or relevant aspects of projects such as the supply chain (Wegelius-Lehtonen, 2001). Despite of the extensive coverage of Lean Construction and Performance Measurement in the literature, the review carried out for this thesis did not revealed a prior measurement system attending the challenging implementation of Lean in the construction industry. The increased attention of performance measurement (Langlo, Bakken, Karud, Landet, & Andersen, 2015) and the frequent existence of Lean implementation attempts in the Norwegian construction industry have motivated the detailed study of these practices in conjunction.

Structure of the thesis

Following is a brief description of the content of the thesis chapter by chapter. Additional summaries with the key findings can be found at the end of each chapter.

Chapter 1 presents the topic and describes the study framework that define the scope of the thesis. As well it describes the foundations about the relevance of the study and the research objectives.

Chapter 2 includes relevant theory of Lean, from its origin and principles until its development as Lean Project Delivery System. The most common Lean practices are presented, including Last Planner, Pull Scheduling, Concurrent Engineering and Virtual Design Construction.

Chapter 3 provides a detailed description of the most popular and extended Performance Measurement frameworks, namely Balance Scorecard, Key Performance Indicators, EFQM Excellence Model ad Lean Six-Sigma.

Chapter 4 extends the Performance Measurement literature to specific frameworks and provides an extensive literature review on the search of indicators for the construction industry and its success factors.

Chapter 5 describes the process followed during this thesis from the definition of the project until the research methodology used for attaining the obtained results. It also includes the research questions, the validity assessment and limitations.

Chapter 6 presents the data collected from the interviews after a first analysis transforming the data in information usable for the creation of results through discussion and comparison. It describes the use of Lean practices, implementation status and challenges, stakeholders' analysis and use of project metrics.

Chapter 7 shows the results created by the author in form of several models based on the information collected. First, I created a model of stakeholders' needs for the correct understanding of the challenges concerning the implementation of Lean practices. Then, I developed the Performance Measurement framework as well as the specific tools, explaining the implementation process as an expression of the linkages between the different elements of the model.

Chapter 8 describes the conclusions of the present work along with specifying its limitations and suggesting directions for future research.

Chapter 2:

Lean Construction

This chapter aims to explain the basics of Lean practices applied in the construction industry in order to provide a ground understanding of Lean. After a brief presentation of Lean principles and core values, the adaptation to Lean Project Delivery System will be described. Then, the most relevant practices used currently in the industry are introduced. Since the origin of Lean practices is in the manufacturing industry, it is important to define and explain how Lean is adapted to the construction industry in order to understand what can be expected in the description of practices used by construction companies.

The roots of Lean

Lean was born as an attempt to improve the production performance in a context of intense competition and demanding customers in Japan. The result was a new methodology created by Toyota engineers translated into a production system. The complete managerial system was described by Womack, Jones, and Roos (1990) and it became popularized among the western industries. Although developed more than 50 years ago, Lean continues being a recognized and respected theory having an influence even further than production industries (Vahos, 2014).

As defined in Vahos (2014), systems' theory can explain the underlying mind-set of Lean by focusing the improvement efforts not only in individual areas, but adopting the view of the system as a whole and focusing on the relations between parts. Rother (2010) lists a number of practices that shape Lean and claims that the core objective of the production system should be to deliver value to the end customer. To achieve this it is necessary to break down and understand the processes as well as their interrelations. The improvement is facilitated by trial and error experiments from people mastering the process. In addition, there should be established specific targets to guide and stimulate employees in the improvement process.

The Lean principles

I will present the Lean principles as described by Womack et al. (1990). First, it should be defined the customers' requirements and expectations as the way they interpret value. Second, identifying the value-stream and eliminating the activities that does not add value is required for the transformation of the process. In this way, the production process is replaced by a continuous flow from the design to the delivery of the product to the customer. Another basic principle is to adapt the production operations to the rate demand of the customer switching from push to pull approach. The last principle is the continuous improvement of the whole process by encouraging employees to seek the perfection in the process.

The new philosophy has been developed through three stages as it can be seen in Figure 2, the fundamental concept of production as flows and conversions, the basic principles already mentioned and a number of methodologies.

Although Lean was created and mostly developed in production settings, it has been several attempts to adapt these principles to other industries such as services or information systems development (Koskela, 1997). Following there is a description of the attempt to adapt Lean principles into a project setting.

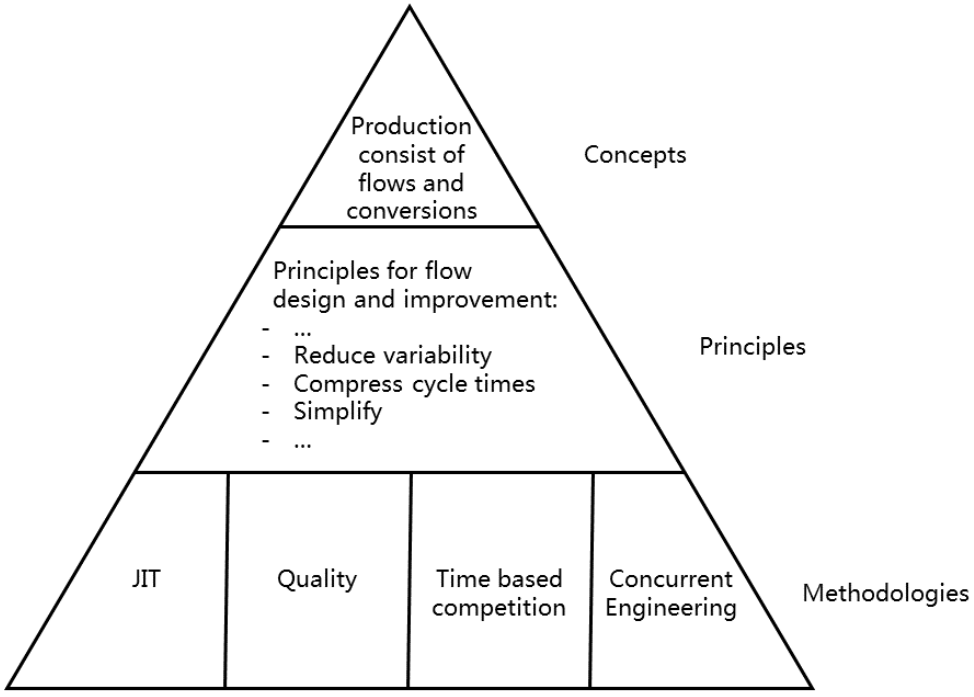

Figure 2: Different levels of the new production philosophy (Koskela, 1997)

Lean Project Delivery System in Construction

The application of Lean practices in the construction industry has been limited and its application incomplete for a long period of time. Koskela (1997) claimed that some of the important barriers for the late adaptation of practices were the presentation of the new approach as specific to manufacturing production, the relative low international competition in construction and to some extent the lagging response from academia. The peculiarities in the construction industry has increased the difficulty in the generalization of concepts, being these peculiarities the one-of-a-kind type of project, site production and temporary creation of multi-organization.

G. Ballard and Howell (2003) presented a model of the Lean Project Delivery System (LPDS) emphasising the differences with traditional systems concerning the definition, relationships and participants on the project phases. The model is shown in Figure 3 and it is explained with further detail next.

The project definition phase under Lean settings is characterized by the involvement of representatives of every stage in the life cycle from this initial phase. This would increase

the understanding of the project and aligning values, concepts and criteria. During the design phase, the practice of selecting options and executing design as soon as possible is switched for deferring decisions until the last responsible moment allowing the exploration of different alternatives. The limit for deferring the decisions is determined by the lead time to realize alternatives discussed. In the next stage, Lean Supply requires the design of the processes that allows the system knowing what to fabricate and when to deliver the components. Lean Supply also intends to reduce the lead time for both information and materials, especially in engineer-to-order products. Finally, Lean Assembly begins after delivery of materials and information and is completed when the client can use the product.

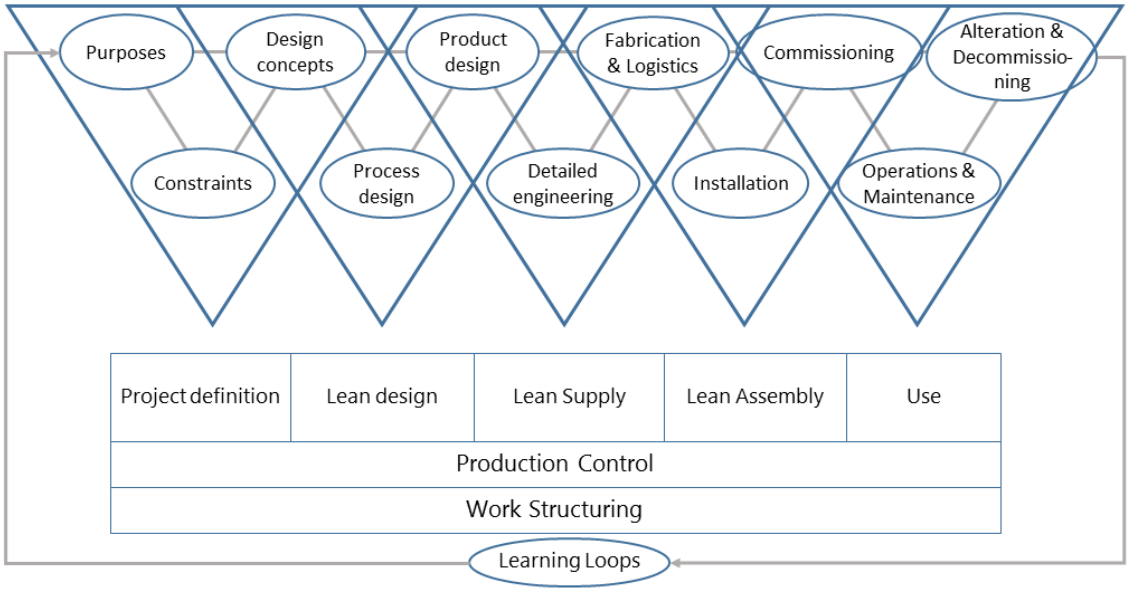

Figure 3: Lean Project Delivery System (G. Ballard, 2008)

The Lean Project Delivery System is adopted in practice in the construction industry through a number of tools and methodologies containing Lean principles. Following there is a description of the practices that are commonly found in Lean oriented organizations within the Norwegian construction industry. These are the Last Planner system (involving planning), Pull Scheduling, Concurrent Engineering and Virtual Design Construction (VDC), also often found as BIM.

The Last Planner

The Last Planner System was created by Herman Glenn Ballard and it is extensively described in H. G. Ballard (2000). It is grounded on the idea that reliable planning cannot be done much before the activities planned in dynamic environments with a high degree of uncertainty and variability. The Last Planner system of production control is found in the industry under a variety of names and with different levels of implementation, and it is the method most often practiced.

The key early finding of the studies from G. Ballard and Howell (1997) was that only around 50% of the tasks assigned in the beginning of the week to construction crews were accomplished according to plan. For this reason the indicator became significant so they tracked the percentage of assignments completed (PPC: percent plan completed) together with the reasons for non-completion on time. Learning from these reasons and incorporating them into the control process would increase the reliability of the plan (G. Ballard & Howell, 1997).

The system is based on four fundamental concepts regarding the assignments to be completed: *should, can, will, did*. Assumed the higher levels of planning being specified, detailed planning contains what *should* be done next. Unfortunately, it is not always possible to perform those activities due to a number of obstacles. Hence is important to look further of what should be done, and be sure that it *can* be done before bringing it to the immediate plan. The planning process then should match what *should* be done within the constraints of what *can* be done, so the activities *will* be performed. By making sure that the task is completed and the obstacles for the next activity are removed, it will be part of what the project *did*.

In order to succeed with the lower level of the planning (Weekly Work Plans on Last Planner terminology) according to what has been described, it is necessary to have a lookahead planning. The main objectives of this lookahead planning according to G. Ballard and Howell (2003) is to shape work flow sequence and match it with the capacity, maintaining a log of work ready to be performed and develop operations' design by detailing how the work is to be done. Typically the lookahead window could extend from

3 to 12 weeks in the future depending on the complexity of the project and the need of several steps in the plan hierarchy (H. G. Ballard, 2000).

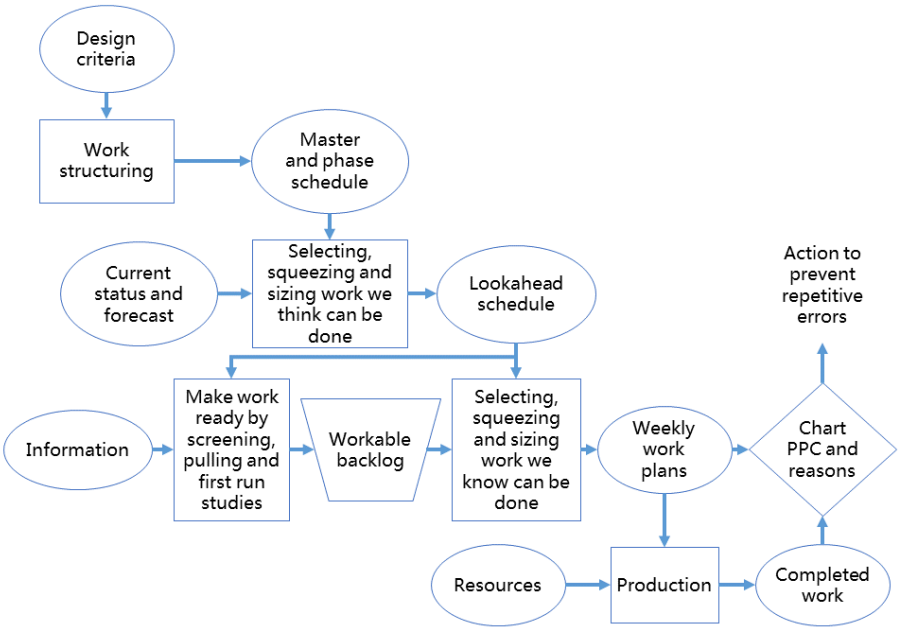

Figure 4: Last Planner system of production control (adapted from G. Ballard and Howell (2003))

The Last Planner system is therefore a set of three specific tools: the PPC indicator and its root reasons, should-can-will-did thinking and lookahead planning. In practice, the level of implementation of each tool varies and companies sometimes find substitutive tools to achieve the same goals. Then different organizations give different names having the same mind-set behind, so it is easier to find Last Planner methodologies under other designations such as involving planning or similar concepts. Although the degree of implementation varies, even partial implementations has shown substantial improvements and waste reduction in projects (G. Ballard & Howell, 2003).

Pull Scheduling

The purpose of Pull Scheduling is to produce a plan that maximizes value generation (G. Ballard & Howell, 2003). In a production context, Bell (2005) emphasises the need for a careful planning in a Lean environment in order to anticipate and smooth variations, allowing flexibility and responsiveness. In G. Ballard and Howell (2003, p. 70) words, a

pull technique '*causes tasks to be defined and sequenced so that their completion releases work'*, eliminating the waste of overproduction.

The process of generating a plan based on pull scheduling is described in G. Ballard and Howell (2003) and it starts by defining the work to be included in the phase and determining the completion date according to the master plan or defined milestones. Then, representatives of those with work packages in the phase meet to do the plan on teamwork basis. First, they should develop a network of the activities required for completing the phase and then start from the completion date and add the activities to the plan backwards incorporating intermediate milestones. Once the sequence of all the activities is established for the first time, the duration of each activity should be applied without considering contingencies in the estimates. After several loops reviewing the logic of the plan in order to try shortening the duration, the earliest practical start date is defined and it can be decided what activities to buffer with additional time according to their degree of uncertainty.

On the execution phase, '*Lean synchronizes release of work to actual demand in real time when requested by a pull signal'* (Bell, 2005, p. 119). In a project environment, the pull signals can be produced by the updated status of activities and its communication to managers and impacted teams so they can react accordingly. An example of these pull signals is the use of boards with the activities to be performed listed in order where workers would annotate the status of the activity and whether is finished.

The use of this practice is less extended than the Last Planner system although it is commonly explained as part of it. The reason for not applying pull scheduling in Last Planner environments can be the need of involving more actors in the planning process, while in practice the planning is done by only one person and then supervised by the manager, or by a reduced number of people.

Concurrent Engineering

A generic definition of Concurrent Engineering (CE) can be extracted from the aerospace industry, where this practice is largely extended.

> *'Concurrent Engineering is a systematic approach to integrated product development that emphasises the response to customer expectations. It embodies team values of cooperation, trust and sharing in such a manner that decision making is by consensus, involving all perspectives in parallel, from the beginning of the product life-cycle.'* (Bandecchi, Melton, & Ongaro, 1999, p. 34)

In the construction context, Jaafari (1997) derived the concept of Concurrent Engineering to be applied specifically in the construction industry defining 'Concurrent Construction', described as '*an integrated approach to the planning and execution of all project activities, from the conceptualization state through to the handover of the facility'.* (Jaafari, 1997, p. 427). According to this approach, concurrent construction is based on the integration of all project phases with the simultaneous inclusion of relevant information from the different specialization areas by the formation of composite teams, and the division of work into separable parts using proactive management and inter-team communication to integrate information from the teams through the life cycle. This description corresponds to the concept of Concurrent Engineering considered in the thesis, although I have preferred to maintain the denomination of Concurrent Engineering to avoid confusion with Lean Construction and to be coherent with the term used currently in the industry.

Concurrent Engineering is also a widely extended practice although is not often realized by organizations, with the exception of those especially focused in this practice. On one hand, those companies emphasizing the use of concurrent engineering usually centred its implementation in the design phase, although it is used throughout the life cycle of construction. On the other hand, companies using concurrency without specifying the name usually use it in the execution phase as a problem-solving tool.

In the framework of describing the new philosophy applied in construction, concurrent engineering is defined as 'an improved design process characterized by rigorous upfront requirements analysis, incorporating the constraints of subsequent phases into the conceptual phase, and tightening of change control towards the end of the design process' (Koskela, 1992, p. 8). Based on this definition it can be recognized the link with the root ideas of Lean methodologies. Aligned with the objectives of Lean, concurrent engineering intends to compress the design time and to reduce the number of change orders by increasing the number of design iterations. The iterative design process allows

overlapping of activities and information transfer between specialization areas, which leads to early finding of problems that can be solved over the iterative loops increasing the design's level of detail. This results in globally shortened design phases with increased quality on the product design (Limon, 2014).

The relevance of the design phase in the value delivery process to the customer is emphasized in the update of the Last Planner system presented by G. Ballard (2008). For this reason, concurrent engineering is a methodology to be considered in future Lean Construction implementation.

In practice, Concurrent Engineering makes use of IT tools to facilitate the exchange and distribution of information between teams and along the project life cycle. An important part of these tools is grouped under the name of Virtual Design Construction (VDC). However, the implementation of CE does not necessarily imply the use VDC and vice versa, thus they are presented separately.

Virtual Design Construction (VDC)

VDC comprises a set of tools that supports the accomplishment of Lean Project Delivery System ideals (Khanzode, Fischer, Reed, & Ballard, 2006). The objectives of these tools include a more effective communication, coordination of various disciplines, constructability analysis, evaluation of logistic plans and creating estimations.

Some of the tools part of VDC are product visualization (3D modelling), process modelling and visualization (4D visualization), and online collaboration tools. VDC allows building virtual models of the product, organization and process in the early phases of the project, before a large commitment of resources is done. This enables the simulation of complexities of the product and understanding pitfalls. Furthermore, it can provide a framework for the integration of data, which allows a fast and iterative collaboration between the different stakeholders involved in the project with the use of concurrent design facilities. Khanzode et al. (2006) provide specific guidelines on the use of VDC tools over the project phases and show some practical examples.

The interaction between the practices presented has been documented over their description. It should be recognized the fact that each practice can be implemented in

different degrees and in combination with other tools, resulting in a wide range of possibilities when describing the practices implemented by organizations. For example, companies implementing Last Planner could use Pull Scheduling or still maintain the traditional method of planning. At the same time of using Last Planner, the organization can use Concurrent Engineering for specific phases of the project or apply it through the whole project life-cycle. Additionally, VDC can support CE practices or otherwise been used independently. This creates a heterogeneity in the use of Lean practices that requires a high degree of flexibility to the frameworks concerning them in order to be applicable throughout the industry.

Summary of the chapter

The roots of Lean are found in the systems' theory, which adopts the view of the system as a whole focusing on the relationships between elements. After its creation in a production context with intense competence and demanding customers, it defines the core objective in delivering value to the end customer. This is achieved through the Lean principles that aim to define customers' expectations, identify the value stream and eliminate those activities not adding value.

The philosophy of Lean was adapted to project-based context as the Lean Project Delivery System, whose main archetype is the Last Planner system. It consist on involving the people who will actually do the work in the planning and ensuring that is possible to do it before bring it to the plan, following a *should-can-will-did* approach. Pull Scheduling, often part of Last Planner, is based on the idea of sequencing tasks so their completion releases work. Concurrent Engineering, considered under the Lean principles, intends to compress the design time and to reduce the number of change orders by increasing the number of design iterations as well as overlapping activities and information transfer. The last tool presented is Virtual Design Construction, which includes process modelling and visualization besides online collaboration tools. VDC enables effective communication and coordination in addition of analytical and estimation capabilities.

Chapter 3:

Performance Measurement Frameworks

This chapter is the first part of the literature review of performance measurement frameworks, which is divided in generic models and purpose-specific frameworks. The present chapter collects the most extended and referenced performance measurement frameworks. These models correspond to general measurement systems applied in a variety of industries and they are used as references in the literature, which are the main reasons for their selection. The importance of having a detailed understanding of these frameworks as well as the way they are implemented is explained because they are used as references for developing purpose-specific models, including the one that I will present as the result of this thesis.

The Balanced Scorecard

Kaplan and Norton developed the Balanced Scorecard (BSC) in the early ‘90s with the aim of exploring new methods of performance measurement (R. S. Kaplan & Norton, 1992). The study resulted in a selected set of measures derived from the strategy of the organization, representing a tool for the communication and implementation of that strategy. The importance of this method is rooted in its ability to bridge short-term leadership action with long-term strategy, and measurement system to strategy through the Strategy Map.

The translation of the strategy into measures is accomplished by using a set of objectives describing what needs to be done in order to implement the strategy. The definition of these objectives is what comprises Strategy Maps. Strategy Maps are the reason for Balance Scorecard to be considered a communication tool, indicating to all the relevant stakeholders what they must do well to achieve the company's ultimate goals.

Measures are derived from the Strategy Map once this has been developed, providing accountability to the system. In this way, performance measures act as a monitoring system to observe the implementation of the strategy. With this purpose and being aware of the importance of intangible assets, R. S. Kaplan and Norton (1992) proposed four perspectives of performance: *financial, customer, internal processes, and employee learning and growth*. Under these perspectives financial measurement is still a base for assessing business' performance, however it is balanced with other measures that show how financial results could be maximized.

Establishing a Balanced Scorecard

According to Niven (2002), the development of the Balance Scorecard should start by developing a guiding rationale that explains the need of such system. This will make easier to engage management and employees in the process. Secondly, the organization need to choose where to implement the BSC. The criteria for the selection of the appropriate organizational unit are having a coherent strategy, executive sponsorship and key managers' support, clear objectives, acceptance of culture of measurement and ability to collect data, organizational scope and sufficient resources (Niven, 2002).

Given the need of developing a new performance measurement system and once made the decision of adopting the Balanced Scorecard framework, the first step is the creation of a team in order to develop the system. Choosing the right people will greatly contribute to the successful implementation of BSC. The amount of people needed in the team will depend on the different areas of the organization, since they all should have representation. There are also some specific roles that are recommended, as an executive sponsor to guarantee the support from the top management, the Balanced Scorecard expert that coordinates the meetings and facilitates the development of the team, and an organizational change expert to mitigate failure risks in the implementation (Niven, 2002). The executive sponsorship is of special relevance to provide deep understanding

of organization's strategy, decision rights to determine priorities and commitment to the strategy. Furthermore, training of the BSC development team should be provided to ensure that all the participants are aware of the process.

Strategy Map

The ability to communicate strategy in a clear manner to all stakeholders is one of most relevant contributions from Balance Scorecard. As the first companies adopting BSC faced some challenges translating strategy into measures, they introduced the definition of objectives answering '*What must we do well in each of the perspectives in order to execute the strategy?'* (Niven, 2002, p. 98). By clearly articulating objectives from the strategy, the task of making the selection of metrics can be facilitated. The Strategy Map is a graphical representation of the mentioned 'what you must do well' which also may reveal important interdependencies among objectives.

In order to develop the Strategy Map, each of the perspectives proposed in the model should be explored in order to develop the objectives rooted in the strategy. The financial perspective is considered as a great 'rearview mirror' and not consistent with intangible assets environment. Despite of this fact, it should be included in the BSC as many practitioners recognize this as of higher importance (Niven, 2002). In my opinion, relying only in financial measures provides few opportunities for improvement but they are still a good indicator to confirm the effectiveness of the actions taken and therefore they should not be completely eliminated from the performance measurement system.

Developing the objectives for the customer perspective might seem difficult to express. Narrowing the answer, this step requires to answer two basic questions according to Niven (2002). First question is 'Who are our target customers?' and the answer should determine which group of customers is the best for the company's products. Second, 'What is the value proposition?', which should describe how the company differentiate itself in the market. There are a number of models for market differentiation (Porter, 1979; Treacy & Wiersema, 1997), however, detailed description of these models are out of the scope of this report.

After determining what the company's value proposition is, the internal process perspective would address how to fulfil it. Niven (2002) claims that this perspective

spawns the largest volume of measures. Therefore the challenge is limiting the measures to those processes that drive value for the customers. Robert S Kaplan and Norton (2004) grouped internal processes in four clusters.

Operations management processes are '*the day-to-day processes by which companies produce their existing products and services and deliver them to customers'* (Robert S Kaplan & Norton, 2004, p. 43). Customer management processes are related to how to maintain and develop relationships with targeted customers. This includes selection, acquisition, retain and grow business with the selected customers. Innovation processes are linked to new product, process and service development. The company should identify opportunities to penetrate into new markets managing a portfolio of research and development programmes, and discern how to bring new products and services to the market. Finally, regulatory and social processes help the company to interact and adapt to the environment where they operate. This includes safety and health practices, employees' engagement and community investment (Robert S Kaplan & Norton, 2004).

Sometimes employee learning and growth is not considered as the highest priority (Niven, 2002). Conversely, this perspective is an enabler of the other perspectives and therefore their objectives should be carefully considered. Motivated employees with the right skills drives the improvement process for meeting customer expectations that often leads to financial returns, therefore acting as the foundations for everything else in the organization. Some possible objectives within this perspective are having the right skills in strategic positions, recruitment talent and adequate training for employees. Within this perspective, information technology systems and aligned organizational culture may play a vital role in the development of employee learning and growth (Niven, 2002).

Performance Measures in BSC

Performance measures in BSC, as in any other framework, communicate to stakeholders value creation and drive their actions. Furthermore, BSC should contain a mix of both leading and lagging measures to show key improvements and their impact on customer satisfaction and financial results. The review of measures will be explained according to the four perspectives that conform the BSC framework: financial, customer, internal processes and learning and grow. In this case, the chosen measures should be a direct translation of the objectives described in the Strategy Map.

Suggestions for measuring the *financial* perspective brought by Niven (2002), account for not overcomplicating measurements and not relying exclusively on measures of growth and profitability. According to the author, although looking for new and missing measures is valuable, often the first measure that come to mind is the most appropriate. As an example, 'improve performance' requires achievement of success over time while often 'monitoring performance' would suffice for the purpose of the objective. It is also important to reflect in the measures that growth is not enough if does not create value. Economic value added (EVA) is suggested as tool for evaluating the opportunity costs and assess the value creation against growth. Other aspects often considered as part of the financial metrics are indicators of risk management, share price and market valuation to reflect the value of the organization's intellectual assets. The key aspect of these metrics is that they are aligned to the company's strategy.

When developing measures for the *customer* perspective, Niven (2002) suggest using the three value propositions of *operational excellence*, *product leadership* and *customer intimacy* as a framework. Operational excellence focus on particular aspects to offer value to the customer. Some examples of these measures could be 'total cost of ownership' or 'price compared to key competitors' in case of operational excellence it is focused on price; 'defect rates' may be monitored in case the focus is on *zero defects* policy. Other areas to focus are growth, selection or convenience for the customer. Product leadership succeed in providing customers with new and innovative products, whose measures would be related to brand perception or functionality of the product. Customer intimacy provides superior services and therefore it could be measured in terms of 'access to key customer information', 'reputation index' or 'customer retention'. Other measures out of this framework can be found, such as customer information based on information shared through Internet or other type of interaction with the customer. However, the most devoted measure in this perspective is 'customer satisfaction'. Although very popular, it can be difficult to actually measure and there is a number of companies where the way of measuring this indicator has led to incoherencies with sales results (Niven, 2002).

Following the framework exposed in the Strategy Map for the *internal process* perspective, some measures will be explored next. Operations management measures refers to routine processes and it can be assessed in terms of 'cycle time' or 'internal lead time'. Customer management can be measured as 'marketing effectiveness', 'number of

customer profiles' or their 'retention'. Innovation metrics related to internal processes are displayed according to budget, 'number of new products develop' or 'introduced' or 'time to market for new products'. Finally, regulatory and social issues can be monitored to show adherence to environmental or social standards and to show actions taken in support of these issues. Measuring this aspect can involve 'number of audit findings' or 'employee volunteer hours' among others. The challenge in this perspective is to identify the processes driving the customer value proposition to define specific measures that enables the correct assessing of its performance. These internal process measures are usually the most tailored indicators, and often new processes are found necessary to achieve the strategic goals (Niven, 2002).

As mentioned in the Strategy Map, employee *learning and growth* is a key aspect of the BSC that will enable the expected performance in the rest of the areas. Employees are a core capital of the organization, and they should be considered as such in the measurement system. The company should identify the competences that needs to be fulfilled in order to achieve the strategy. Thus, the coverage of these competences could be used as measure of employees' skills development. Another common practice is to have personal development planning for every employee, which may allow measuring the extent to which employees are adhered to their planning or the coherence with the competences needed. In the same line, metrics about employee training can give an idea of the development of competences when measured the results of the training rather than the training itself.

Other forms to measure employee learning and growth is the access to relevant information according to the position of the employee. Therefore monitoring 'capital information accessibility' requires first to determine what information should be available for every stakeholder. At an organizational level, 'employee satisfaction' can give an idea of their motivation. This is a key measurement of personnel engagement, which is a basic condition for achieving their goals. Measuring employees' wealth can be also relevant, since aspects like a healthy lifestyle can have an impact on safety. This could be considered as an example of leading indicator in contrast with injury frequency rates, given that a significant percentage of mortality is related to lifestyle choices (Niven, 2002).

Final notes on Balanced Scorecard

One of the questions that raises when selecting the performance measures is the amount of measures needed. Although is not possible to give a specific answer to this question, the system should contain all the measures necessary to describe the strategy adequately. At the same time, if you can describe your system with fewer measures than you have, then you should stick to the minimum. These criteria will facilitate getting information from the system and make it cheaper to maintain.

Given that the selection of measures is performed, it is helpful to develop a 'data dictionary' to distribute the system with the executive team and the rest of the organization. This will be a reference to provide the necessary background for everyone in the company to understand the logic of the system, enabling the engagement to the initiative and its correct deployment.

The definition of measures should be followed by setting targets in order to evaluate performance against a goal. Niven (2002) describes three types of targets. Long-term goals are often described as BHAGs (Big Hairy Audacious Goals) and they represent a monumental challenge that is used by the organization to stimulate progress. Midrange targets normally apply to a wider variety of activities and do not represent discontinuous operations. Nevertheless they establish a remarkable goal providing a powerful stretch target for the organization. Finally, incremental targets are set on the short term (about one year), and they give a quantitative goal for the decided measures and act as an early warning in case there is a deviation from the future expected performance.

The Balanced Scorecard developed in the first term should be cascaded to lower levels of the organization. This will create an aligned version of the BSC for each business area, departments, projects and teams. Lower level Scorecards will often include issues related to their specific challenges and opportunities within the area. For this reason is important to involve employees from the areas that BSC relate to. The strategy should come from the upper level of the BSC, but the adaptation should consider insights from the employees. To achieve satisfactory results, an extensive communication programme is needed to ensure employees fully understand the Balance Scorecard creation process and the strategy defined in the Strategy Map (Niven, 2002).

The lowest level where the Scorecard should be applied depends on the culture of the company. Reaching personal measurement may have some drawbacks as the misuse of the system as punishment base (Andersen & Fagerhaug, 2002). On the contrary, it may help to define personal objectives for the career development of employees according to their capacities.

Key Performance Indicators, KPI

A number of organizations have worked on elaborating a common set of Key Performance Indicators within the construction industry (Beatham et al., 2004). However, the first aspect to mention about the KPI is that they need to be part of a system. If the results obtained do not lead to actions taken, it would make no sense to measure (Bourne et al., 2000). The Egan report, Construction Best Practice Programme (CBPP), the ACE consultants or the Construction Industry Research and Information Association (CIRIA) have developed their own set of indicators, although their most significant problem is that they do not offer the opportunity to drive actions (Beatham et al., 2004).

In this thesis, the model presented by Parmenter (2010) is taken as reference to explain what Key Performance Indicators are and how they can be implemented. In order to provide a common understanding of concepts, a set of definitions will be given first followed by further discussion of concepts regarding the characterization of indicators. Finally, the foundations and steps of the implementation process of KPIs will be explained.

Definitions

Before explaining the details of Key Performance Indicators it is worth defining the basic concepts that will appear to establish clearly the differences between the terms. This is not a trivial question since different authors may use significantly different meanings for similar concepts and this can lead to confusion. In this thesis, the reference that will be used is the model from Parmenter (2010). Furthermore, the definitions will also try to explain the relations of these terms to the ones used in other models also present in this study.

Key Performance Indicators, KPI

According to Parmenter (2010, p. 4), '*KPIs represent a set of measures focusing on those aspects of organizational performance that are the most critical for the current and future success of the organization'.* Some of their main characteristics from this definition are that are non-financial measures, are frequently measured (monitored) and they encourage appropriate action.

On the contrary of Parmenter, the definition provided by Radujkovic, Vukomanovic, and Dunovic (2010) on the EFQM Model, KPIs are defined according to their ability to change the outcome, separating measures in leading and lagging. Thus, they equate KPIs to leading measures. This characterization will be further discussed in the next chapter.

Key Result Indicators, KRI

Often mistaken for KPIs, KRIs are measures from the outcomes of many actions providing information about whether the company is going in the right direction. These measures usually cover longer periods of time than KPI and are reviewed with less frequency. The main difference between KRI and KPI is that Key Result Indicators should be directed to take governance decisions, while management decisions should be grounded in a mix of KPI, RI and PIs (Parmenter, 2010).

This definition is aligned with the Key Performance Outcomes (KPO) from the EFQM Excellence Model, although this model does not consider a lower scale of Result Indicators. At EFQM Model, KPO indicate only that are measures not able to affect the outcome (Radujkovic et al., 2010).

Performance and Result Indicators, PI and RI

Performance and result indicators are those measures that while important, are not key to business success. Rather they help teams to be aligned with the organization's strategy (Parmenter, 2010).

The question about the appropriate amount of indicators is complex and every author has his own opinion. Parmenter (2010) collects the suggestion from Kaplan and Norton

recommending no more than 20 KPIs, or Hope and Fraser suggesting fewer than 10. He propose the 10/80/10 rule, meaning up to 10 KRIs, 80 RIs and PIs, and 10 KPIs. From the 10 KPIs, Parmenter (2010) suggest continuous monitoring of 1 or 2 KPIs by management.

Critical Success Factors

These are the main aspects of organizational performance that determine the ongoing health of the company (Parmenter, 2010). This definition could be linked with the process measures from Andersen and Fagerhaug (2002) model, which determines two types of measures, result and process. Result measures focus on measuring achievements, while process measures '*describe certain important characteristics of a process and are assumed to have an effect on the desired result'* (Andersen & Fagerhaug, 2002, p. 93). The authors mention this separation as illustrating the difference between Western and Japanese thinking. Western management culture typically emphasizes measurement focused on achievements, while Japanese attitudes focus on improving the performance of the process as the way to obtain the desired results.

Categorization of Indicators

One of the first question raised when introducing the concept of KPI is the categorization of indicators. This categorization is usually made based on the ability of indicators to provide direction for decision-makers. There has been identified three different categorizations of indicators. The most common, adopted by many authors is the definition of lagging and leading indicators (EFQM, 2012).

The EFQM Excellence Model, which will be explained later on, divides the indicators in three types of measures. KPI, which indicates performance of associated processes and can serve as an early warning, being identified as leading indicator because it provides an opportunity to take corrective action. Key Performance Outcomes (KPOs) do not offer opportunity to change since they are the result of a completed process. They are connected with lagging measures given that the results from KPOs could only be used to change how the next processes are carried out (Beatham et al., 2004). Finally, perception measures can be leading or lagging depending on when the measure is taken. For example, if customer satisfaction is measured at the completion of the project, it will be

considered a KPO and thus a lagging measure. On the other hand, when customer satisfaction is measured periodically along the development of the project, it would allow corrective action and therefore being a leading KPI.

According to Parmenter (2010, p. 10), '*lead and lag labels are not a useful way of defining KPIs'* because is very often complicated to define whether an indicator is leading or lagging. The same indicator can be seen as any of the perspectives depending on who is assessing the indicator since it can actually be both of them. He propose to label the indicators as past-, current-, or future focused measures. Current-focused measures are those ones monitored continually, as for example current amount of delays in the transport. Future-focused measures account for aspects where the action has not taken place yet. An example of future-focused measures can be meeting programmed or date for the next product launch. Past-focused measures refer to actions in the past.

Andersen and Fagerhaug (2002) proposed another classification according to the purpose of the measures. They divided the measures in result, diagnostic and competence. Result measures show what the company is achieving without specifying how it was achieved. Diagnostic measures indicate future results, and they are indicators of success factors and often show to some extent where to improve. Finally, competence measures define the organizational position to meet future challenges. This classification also indicates a validity horizon for the different measures, and it can fit together with Parmenters' classification as illustrated in Figure 5, which combines both perspectives.

From my personal experience providing feedback to highly motivated students about their creatively developed indicators in the performance oriented management subject, the amount of indicators that can be discussed as leading or lagging depending on when they are measured makes me consider that the Parmenter's perspective is the one that can provide the most clear difference among indicators. This perspective can be combined with Andersen and Fagerhaug's classification to provide full categorization of the different measures.

Foundation Stones of KPI

This section collects the key aspects of implementing KPIs, including partnership with key stakeholders, transfer of power to the front line, measuring only what matters and

linking performance measures to strategy through critical success factors (Parmenter, 2010).

Partnership

Organizational change require that the need of change is understood and accepted by all stakeholders. As described previously about mental models on organizational learning, stakeholders need to be engaged in the 'ladder of inference' to reach the common understanding of the change needs (Senge, 2014). As a result of this common understanding, it is possible to develop jointly a strategy for the introduction of KPIs (Parmenter, 2010). The partnership should be extended to key customers and key suppliers, adopting a value chain perspective in the implementation process.

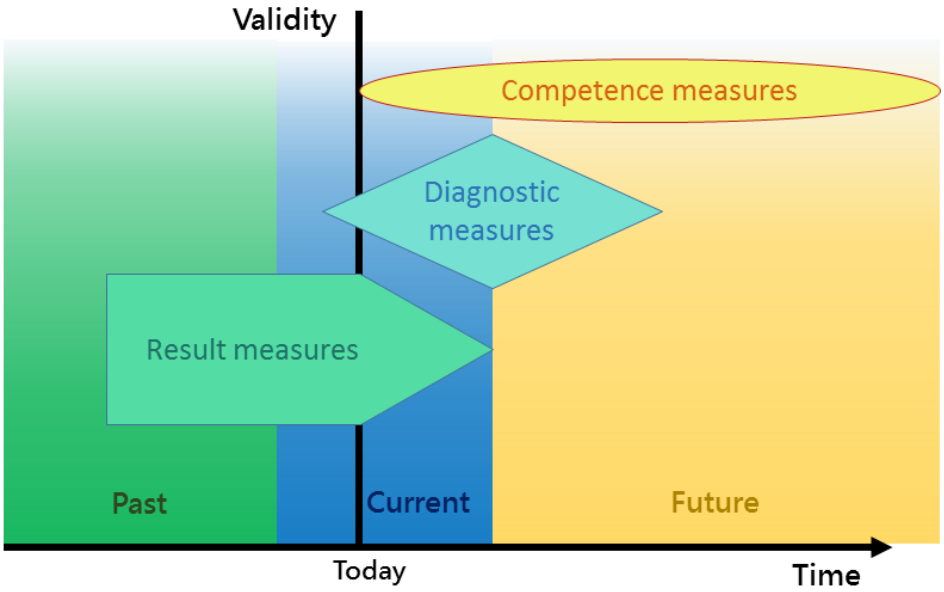

Figure 5: Focus and validity horizon of measures (adapted from Andersen & Fagerhaug, 2002)

Transfer the power to the front line

This foundation stone requires effective top-down and bottom-up communication, the empowerment of employees to take immediate action to rectify situations affecting KPIs and teams being responsible to develop and select their own performance measures, which might require training on KPI issues and support to those with specific difficulties (Parmenter, 2010).

Measuring only what matters

As mentioned before, a performance measurement system that does not lead to any action is meaningless. '*The performance should be measured in a way that results in action'* (Parmenter, 2010, p. 33). This implies that every report should be connected to a success factor and it is measured only what is needed. If the amount of reporting is reduced it is easier that the results of what is reported lead to an action. Therefore the reporting activity should be adequate to the organization's ability to take action on those reports.

Linking performance measures to strategy

Following the foundation of the Balanced Scorecard, Parmenter (2010) claims that the KPIs should be linked to organization's strategic objectives through its organizational success factors, which should be at the same time linked to the balance scorecard perspectives (including employee satisfaction and community and environment, as will be explained next). Given the limited ability of an organization to handle a certain amount of strategies at a time, there should be not more than eight critical success factors. As presented by Andersen and Fagerhaug (2002), the house of quality can be a relevant method to find the most appropriate success factors to focus based on the organization's strategy.

KPI Model

Parmenter (2010) makes use of the Balanced Scorecard model as the first reference, and to the formulated perspectives (Financial, Customer, Internal Processes, and Learning and Growth) he adds two more, Environment and Community, and Employee Satisfaction. Environment and Community refers to the support of local businesses, future employment and community leadership, while Employee Satisfaction is linked with positive company culture, retention of staff and recognition as employer. The foundation for adding these measures is that the community should be seen as the main source of future employees and possibly partners and customers (Parmenter, 2010). Based on these perspectives, Parmenter (2010) describes a 12 step model for the implementation of KPI, although some of them can be merged. Table 1 shows the steps of the model, which will be summarized next.

Table 1: A 12 Step Model for Developing and Using KPIs (Parmenter, 2010)

Developing and Using KPIs
1. Senior Management Team commitment
2. Establishing a KPI Project Team
3. Establishing a 'Just do it' culture
4. Setting up a holistic KPI development strategy
5. Marketing the KPI system to all employees
6. Identifying organization-wide Critical Success Factors
7. Recording Performance measures in a database
8. Selecting team-level performance measures
9. Selecting organizational winning KPIs
10. Developing the reporting framework at all levels
11. Facilitating the use of KPIs
12. Refining KPIs to maintain their relevance

Step 1: Senior Management commitment. They need to create a sound environment in the company for the implementation of KPIs, for which is necessary first to get them convinced of the importance of monitoring KPIs. This means that they should be ready to provide feedback on critical success factors and ensure support to build the report systems. According to Parmenter (2010), it is especially important to involve the CEO personally being a central driver. Moreover, this project requires a public relations function behind to sell the implementation company-wide as a positive experience that will improve working life. It is proposed to have a workshop with the Senior Management Team to help the constitution of a KPI project that will cover the main institutional barriers.

Step 2: Establishing a KPI project team. A small, well-trained project team formed from two to four people reporting directly to the CEO should be established. The team should be balanced and have linkages with the different business processes of the organization. This team should receive appropriate training and be supported by the senior management.

Step 3: Establishing a 'Just do it' culture. The project team should adopt a culture in which decisions are taken to avoid delaying the process. It should be assumed that the system will not be perfect from the first time and will require certain adjustment. The presence of an external facilitator can help to keep the decision-making process ongoing while maintaining the process in-house.

Step 4: Setting up a holistic KPI development strategy. This means to draw an overall strategy for organizational change to guide the implementation process, which will be influence by organization's size, diversity of business units and resources available. In this step is necessary to be aware of the existing measurement culture and plan a phased implementation that contributes to organizational change. Through this step, a coherent approach should be achieved to get the commitment from all the stakeholders.

Step 5: Marketing the KPI system to all employees. The purpose of this step is to convince employees about the need of change and attract their interest to participate reducing their resistance. It is important to address at this time the employee's concerns about the system, as it could be used to allocate blame, and show the future benefits of the system, as making work more rewarding and increased autonomy.

Step 6: Identifying organization-wide Critical Success Factors. Parmenter (2010) suggests to first interview the senior management to collect all the success factors, to later on dedicate a two-days workshop with part of the management and experienced staff to decide the critical success factors and its relevant KPIs. Once a reduced set from five to eight success factors has been identified, they would brainstorm to find the KPIs. After wide consultation, these critical success factors will be explained to the employees. '*If staff are told what is important, they can align their daily activities to maximize their contribution'* (Parmenter, 2010, p. 212).

Other models, such as the one described by Andersen and Fagerhaug (2002) have a slightly different approach to find the KPI that is worth to mention. Their approach build up KPIs from the business processes that better support the achievement of the strategy. Therefore, it is necessary first to identify and map the processes and the expectations from the different stakeholders defining the performance requirements. This results in a list of business processes ranked by its relative importance regarding performance requirements.

In this way, the process of defining key success factors is more structured although the process of finding KPIs remain in both cases as an exercise of creativity. For this reason, brainstorming is used in both cases for finding the KPIs.

Step 7: Recording performance measures in a database. This database should be made available to all employees so the teams select the success factors relevant to them and allowing input of new measures. Training to the teams about how to use the database and refine performance measures should be provided. It is important that the database is constantly updated with the attributes measured and it contains all the performance measures connected to the success factors.

Step 8: Selecting team-level performance measures. The KPI project team should provide information to all teams on how to select their own performance measures aligned with organization's critical success factors. It should be encourages to use a mix of past-, current-, and future-looking measures. It will be necessary to categorize the selected measures according to the time horizon and result or performance indicators. When these indicators are related to several scorecard perspectives and are common to a number of teams, they can be considered as KPI or KRI. Teams should be allowed to evolve the measures agreed, as it will often take some refinement to achieve the perfect set of performance measures. This step can help to clarify team's objectives and feel the ownership of the performance measures.

Step 9: Selecting organizational winning KPIs. After the selection of indicators have had certain progress, is time to start developing organizational KPIs. This is an iterative process in which findings are communicated up and down to ensure the cascading relationship of measures. This approach is a clear example of empowering the front line of the organization. Critical success factors found in step 6 should also influence the definition of KPIs. Once KPIs are defined, they should be tested to ensure that they produce the expected behavioural outcomes, resulting in an effective set of balanced KPI, KRI, PI and RI.

Step 10: Developing the reporting framework at all levels. The reporting framework should support the timely decision-making, for which a hierarchy of reports and empowerment of staff is required to take action when issues affect the KPIs. The

frequency of measurements' reviews is critical in this aspect, and should not rely completely on regular meetings because it would not allow taking immediate corrective action. Parmenter (2010) emphasizes the role of the CEO when there is a deviation in the KPI that are being monitored and he claims that the CEO should ask for information about the causes of the deviation to encourage the corrective actions.

Step 11: Facilitating the use of KPIs. Once adopted the KPIs, it is important that they are incorporated into organization's culture to avoid its failure when key personnel move on. The company should dedicate resources to communicate the system and educate in the measurement culture. Measures should allow comparing against other organizations, thus some measures relative to competitors are encouraged. Another aspect of the use of KPIs is the need of establishing certain targets for the measures. However, it is more beneficial to establish an acceptable range rather than a specific target, since the range can be more tolerant with changes in the environment.

Step 12: Refining KPIs to maintain their relevance. The improvement process will need to change priorities areas as previous focus areas are mastered. Some KPIs will be always maintained due to their relevance to success factors. At the same time, critical success factors should be reviews periodically especially in changing environments. This process will enable continuous improvement and will ensure that the KPIs are always aligned to organization's strategy and its environment.

Final notes on the KPI Model

As it is being explicit, KPIs are not a model in itself and looking for these measures without certain preparation and being part of an analytical process will not lead to performance improvement. Furthermore, creating a set of KPI is not a trivial question and will need an iterative process to find a balanced set of indicators. As important as finding these indicators is the implementation process. The team ownership of measures and the communication of critical success factors is essential for aligning employees' behaviour. Moreover, the measures should allow taking action at operational level while being reported to management in case of KPIs for following up performance with the required frequency. Finally, the periodic update of the system and its integration in the organization's culture is a 'must' to ensure the future relevance of the system.

EFQM Excellence Model

EFQM stands for European Foundation for Quality Management and it is an initiative born in 1991. The purpose was to provide a model for self-assessment of organizations based on Total Quality Management principles to achieve continuous improvement of practices. It is a general model intended for all kind of organizations, business and governments (Gasparík, Gasparíková, & Ellingerová, 2014). The EFQM can be compared with similar initiatives such as the Baldrige Performance Excellence Program from USA, and the Japan Quality Award Council.

Fundamental concepts

There are a number of concepts defining the basic attributes of an excellent organization, which are described on EFQM (2012). This means that these attributes contribute to achieve outstanding levels of performance according to stakeholders' expectations. Among the stakeholders, customers should have a privilege position when analysing their needs since they are the objective of most of adding value activities in the organization. Creativity and innovation are basic steps for increasing value and performance, which requires engaging other stakeholders throughout the value chain.

Excellent organizations should increase their capabilities while being sustainable in terms of economy, environment and social conditions. This requires a leadership founded in long-term vision, integrity and responding effectively to opportunities and threats. Creating a culture of empowerment is key for achieving both organizational and personal goals, which at the same time will contribute to sustain the outstanding results in organization's operational environment (EFQM, 2012).

EFQM Model

Vukomanovic, Radujkovic, and Nahod (2014) claim that the main purpose of the model is to assess company's excellence by identifying deviations from best practice according to nine criteria. These are divided into enablers and results. Enablers indicate what the organization does and how it does it, while results cover the organization's achievements. Each criteria is weighted for a final score. Some authors suggest that these weights would need to be adapted in the construction industry (Vukomanovic et al., 2014). However,

this would eliminate the possibility of benchmarking between industries, missing one of the main benefits of the model.

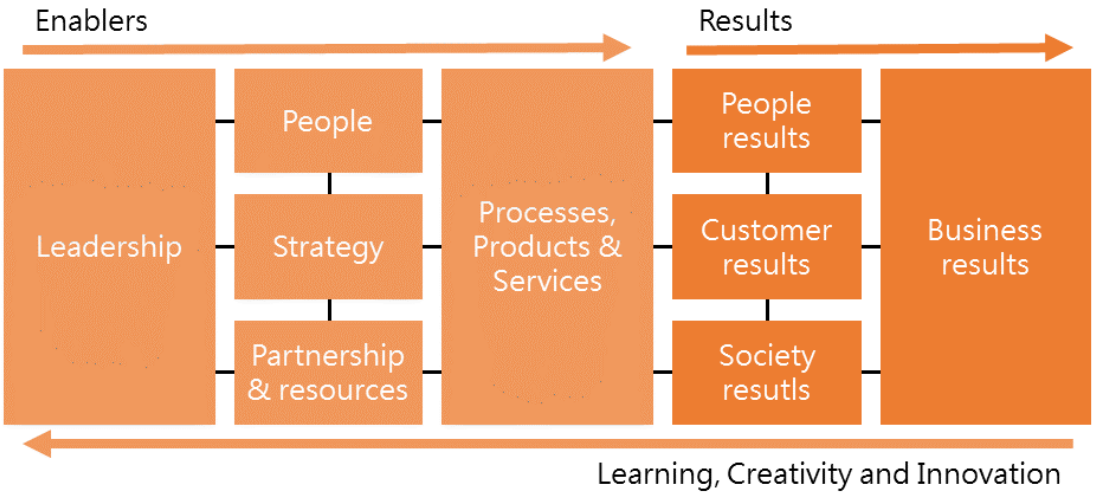

Figure 6: The EFQM Excellence Model

Enablers

Starting by the enablers, leaders of excellence organizations establish a clear vision of the organization in its context and they instil the values and the culture. As well they should act as role models of integrity, social responsibility and ethical behaviour. Their core tasks is the communication of vision, mission, values and culture effectively and they also act as agent of change promoting and driving the change.

'Having decided on its policy and strategy and ensured that its people, resources and partnerships are capable of supporting them, it then defines its processes which will deliver its customer results and its own key performance results. In delivering these results it also affects the employees (people results), and also the society in which sits (society results).' (Beatham et al., 2004, p. 100)

Through the strategy is defined the future direction of the company, which need to be communicated throughout the organization while making it relevant to the people by cascading down to reach specific objectives related to teams and individual tasks. The EFQM Excellence Model provides a specific sheet for the assessment of the strategy and suggest a number of tools for stakeholder identification and communication of strategy.

The affirmation that people is often the most important resource that an organization has is used in the model to inspire the need of planning, managing and improving people's knowledge and competence within the company. This should be done according to what the organization wants to achieve, which is described in the strategy. Other aspects are the need of choosing the right people considering not only their qualifications but also their attitude, and develop the competence through training, self-learning or mentoring programmes. Empowering people through team building and expanding people's horizons can bring more flexibility and robustness to the organization against unexpected events (EFQM, 2012).

If this is applied to external partners can be an effective way to support the organization's strategy. These relationships should be built based on mutual trust, respect and openness. By attracting the appropriate partnerships, additional added value can be provided to the organization by reducing time-to-market, facilitate innovation and technology use or reducing costs.

Process, product and services enabler is based on the idea that the organization's business model is defined in terms of core capabilities, processes, partners and value proposition. Identifying stakeholders' needs helps to define the key processes, which should be mapped in a model. This will help to identify the critical success factors and establish adequate measurement to monitor and improve the overall performance. The model provide some clues for this process, although more detailed description of tools for process mapping can be found in (Andersen & Fagerhaug, 2002).

Results

The first element when analysing the results is the customer, which is the one that assess the quality of the product or service. Excellence organizations invest resources in understanding customer requirements, which should be delivered by establishing adequate processes. Customer results are the reported outcome of these processes.

The EFQM model provides a classification of indicators dividing them into leading and lagging, and it separates Customer Results according to this categorization, containing customers' perception of the organization the majority of lagging indicators.

Performance indicators are internal measures used to monitor, understand and predict performance for the organizations' external customers. The measures of customer results should cover a wide extent of organization's functions, locations and products without neglecting important aspects of its offerings. The EFQM model mention that effective organizations establish specific targets to specific indicators and analyse trends to ensure sustainability rather than short-term results. The use of benchmarking under an appropriate methodology may have a significant effect on the improvement of customer related processes (EFQM, 2012).

Based on the previously mentioned importance of the people as a major resource for the organization, it can be argued that people without job satisfaction in terms of motivation and commitment cannot provide the customers with expected service. For this reason, the company has to make available the facilities, tools and techniques to do their job properly as well as to satisfy the employees' concerns both in the short-term and in their career development.

The model includes two type of measures about their employees according to EFQM (2012). First, perception measures seek to find out how people in the organization feel about themselves, their job and the organization. The assessment can be based in factors like motivation and satisfaction, being necessary to understand the importance of the issues measured. Second, performance measures on the employees are categorized into five sections including engagement, competency, leadership, career development and internal communication. Nevertheless, the most important fact about measuring people results is to provide them feedback, which can be used as a basic tool for getting them involved in organization's goals.

The EFQM model extends the definition of excellence to conduct the business ethically and having a positive impact with the different groups of the society. Social and environmental issues are increasingly considered from the customer and are able to bring real value to shareholders.

Society results start by developing a strategy that includes the management of organization's relationship with the different actors in the society. Making the approach to society and environment explicit, gives already a strong message to stakeholders.

Similarly as in previous results measurement, the perception of the organization and the performance indicators are the two basic elements. These measures are used to quantify the degree of deployment of policies and assess the improvement efforts among organizations (EFQM, 2012).

The business performance results make use of Pareto principle, also known as 80/20 rule, in order to reach the highest impact with the appropriate effort and resources. This should be applied in the first term to what should be measured delivering the Key Performance Results, emphasizing that the business outcomes go further than merely financial results. The EFQM model suggest that the perspectives from the Balanced Scorecard more linked to business results are internal processes and learning. The previous results are collected in a rigorous scoring framework named RADAR scoring matrix, which will be explained next.

The RADAR logic

The previous criteria described are the areas where the organization have to perform in order to reach excellence. The question comes on how to evaluate those criteria, and it is answered with RADAR logic. It states the need of the organization to determine the Results that are aiming to achieve according to its strategy. It also needs to plan and develop the required Approaches to deliver those results, and Deploy them in a systematic way. Finally, the organization needs to Assess and Refine the approaches by monitoring and analysing the results (EFQM, 2012).

Enablers are assessed according to the approaches that have been adopted and how they were deployed throughout the organization. Then, the organization should assess the efficiency and effectiveness of these approaches and refine them in case of improvement is needed. On the other hand, results are evaluated based on their relevance to the organization's strategy and to what extent they reflect the progress of the key objectives. Moreover, the actual performance of these results should be assessed in terms of trends, targets, comparisons and causes. Finally, the RADAR logic is a cyclical model that serves as platform for continuous improvement processes and the way to develop capabilities and sustain excellence (EFQM, 2012).

Final notes on the EFQM Excellence Model

The EFQM Excellence Model is a very extensive framework that comprises a very structured sequence to find the most relevant KPI for each organization in every industry. The model includes a set of five different approaches to self-assessment depending on the level of maturity of the excellence model within the organization (Beatham et al., 2004).

The benefits obtained from the model are mentioned by Vukomanovic et al. (2014), being the first one that companies found EFQM easier to use than other models. Its immediate benefits are benchmarking opportunities, continuous improvement and employees' engagement. It has also a component of marketing strategy, internal regarding a common approach to improvement across the company, and external having a positive impact on how the organization is perceived. Long-term benefits account for reducing costs, balance short- and long-term investments and develops a holistic approach to quality issues.

Gasparík et al. (2014) describes the problems found in the application of the model after studying the implementation process in the construction industry. The main criticism of the model is that although it seems simple to understand, its application is a complex, time-consuming process, often needing the use of qualified external consultants. At the lower levels of the model, the EFQM contains a series of sub-criteria requiring a very detailed description of the functioning of the organization, and they are often misunderstood by the management. Other criticism is that the whole process is too bureaucratic, which makes organizations fail to record the results despite of being sufficiently accomplished. Furthermore, the incorrect definition of processes and results in the report delivered to EFQM professionals may result in a low score, whilst might be an otherwise successful organization. Vukomanovic et al. (2014) also mention among its criticism the inability to connect with organization's strategy and weak relationship between causes and consequences in business processes.

The involvement of Norwegian companies as EFQM members is very low, with only one representative and the construction industry in general has also a unique representative, although consultants groups are very widely represented and they could have direct involvement in the construction industry.

Summing up, the EFQM Excellence Model brings the possibility of benchmarking among all kind of industries and sectors, which is not a trivial question. It is also a very solid framework, developed by experts in close cooperation with different partners in the European industry. Hence it worth to be considered as a reference for developing other purpose-specific measurement frameworks considering its benefits and limitations.

Lean Six-Sigma

The last framework that will be considered is named Lean Six-Sigma. As a difference from the previous frameworks, this is not focused on the elaboration of indicators to drive the continuous improvement. Lean Six-Sigma is rather centred on the detailed analysis of processes and customer needs to identify the waste and allocate the possibility of improvement. Moreover, current experiences with Lean Six-Sigma have been on manufacturing industries, retail and services. For this reason, the achievements on reducing cycle times are often associated to cost reductions, which is very significant after a threshold of cycle time (M. O. George, 2010). In order to achieve those benefits, it is necessary a careful prioritization and selection of projects in the application of Lean Six-Sigma. The advantage of LSS is that provides the ability to cost reduction without decreasing the ability to meet customer needs (M. O. George, 2010).

In order to better understand how Lean Six-Sigma works, the value proposition of the model will be explained, including the reasons for mixing these methods together. Once these aspects are understood will be possible to reach a conclusion about the hypothetical use of Lean Six-Sigma in construction.

The Lean Six-Sigma value proposition

The Lean Six-Sigma principle can be described as follows:

> *'The activities that cause the customer's Critical to Quality issues and create the longest Time Delays in any process offer the greatest opportunity for improvement in Cost, Quality, Capital and Lean Time'*. (M. L. George, Rowlands, & Kastle, 2006, p. 2)

Based on this principle, LSS is able to provide answers about the priorities for improving processes, and to what extent can these processes be improved according to the biggest

opportunities for enhancement. LSS is also able to link improvements in quality, process speed and lead time with shareholder value, making easier decisions of capital investments on LSS projects (M. L. George et al., 2006).

If Lean is considered on its own, it will be possible to achieve better cycle efficiency by removing 'waste' in Lean terminology. '*Lean means speed'* (M. L. George et al., 2006, p. 39). However, by using only Lean is not possible the statistical control of processes. Six-Sigma is a management system based on measuring process capabilities in order to achieve top performance that benefits business' customers and shareholders. Nonetheless, Six-Sigma alone does not allow dramatic improvement of process speed. By setting together Lean and Sig-Sigma, LSS provides a '*methodology that maximizes shareholder value by achieving the fastest rate of improvement in customer satisfaction, cost, quality, process speed and invested capital'* (M. L. George et al., 2006, p. 6).

Use of Lean Six-Sigma

When a new methodology is presented it exists the risk that organizations do not spend time considering the purpose of its implementation, and it is possible that these methods are not suitable to all type of problems in all situations (M. O. George, 2010). LSS is not designed to answer strategic questions and requires a specific problem to be addressed. M. O. George (2010) presents some situations where LSS is not recommended for several reasons. It requires an important amount of resources in training and analysis of problems, and it is only solve problems related to improvement of processes. When a reasonable potential solution is found, it is recommended to establish a project to implement that solution and verify its effectiveness. In contrast, M. O. George (2010) claims the validity of LSS under unclear problem's reasons or challenging goals linked to business priorities.

Although Lean Six-Sigma has been tested in different industries such as manufacturing, retail and services (M. O. George, 2010), its application on the construction industry is scarce (Raid, 2012). Its use for improving production planning in residential construction is an example (Beary & Abdelhamid, 2005). Although LSS implementation has an impact on speed, production planning and control receive the greatest benefits (Drohomeretski, Da Costa, De Lima, & Garbuio, 2014). Since the problem in these areas in construction have been sufficiently addressed by practices such as Last Planner, it is preferable to avoid greater use of resources. Also, its impact can be limited due to the project based context.

Summary of the chapter

Four different frameworks are selected based on their relevance both in the industry and in the literature, and because they are used to develop the model resulting from the thesis.

The Balanced Scorecard was introduced by Kaplan and Norton with the aim to facilitate the implementation of the strategy in organizations through a performance measurement system. The key contribution from this model is the ability to communicate the strategy through the organization articulating the clear objectives from the strategy (Strategy Map). Then, the indicators are defined according to four perspectives: financial, customer, internal processes and learning and grow.

Key Performance Indicators focus on the generation of meaningful indicators for the organization. The framework defines and differentiates between concepts such as key performance indicators, key result indicators or performance and result indicators. Then, they are categorized according to their time horizon (past-, present- and future-focused indicators). The model explains the steps for developing and using the KPIs. Its limitation is that it is not linked to other parts of the organization and neither defines a framework for benchmarking. However, it can be of great utility when generating the indicators.

The EFQM Excellence Model is a self-assessment tool based on TQM principles. It contains two branches, enablers (providing the context to introduce core values and culture) and results (analysing the outcomes and their impact on customers, people, society and business results). The RADAR logic provides an evaluation framework to deliver the continuous improvement. The benefit of using the EFQM model is that provides a base for inter-sectorial benchmarking.

Lean Six-Sigma is centred on the analysis of processes and customer needs to identify the waste and allocate the possibility of improvement. Its implementation is often limited to manufacturing because of the use of statistical methods for assessing the process that has been more restricted in other industries due to the great amount of resources required. However, this model brings some important concepts as the association Lean-speed and Six-Sigma-statistical control as well as a powerful tool for identifying improvement gaps.

Chapter 4:

Performance Measurement Research and Organizational Change

This chapter is divided in two parts. The first part presents the performance measurement frameworks developed by the academia for specific purposes, which are often derived from the previously presented generic models. They are important for the development of this thesis because they point out what aspects are central in the construction industry and they present a number of indicators that could be used in the resulting model of the thesis. This section covers the detailed literature review on purpose-specific measurement frameworks and KPIs for the construction industry, which I chose to present in a table format for ease comparison. In order to show the evolution of project success factors towards construction-specific factors, I will present a chronological overview of these success factors, which can help finding appropriate project metrics.

The second part of the chapter includes organizational factors related to the implementation of new methodologies within companies. Although the complete implementation is out of the scope of the thesis, it may have a large impact in the design of the measurement model. The challenges in the implementation of Lean and measurement systems are documented and a mental model is described as an explanation of how individuals can change their attitudes, which will be a relevant argument in the discussion.

Performance Measurement Research

The most common performance measurement and management frameworks have been presented in the previous chapter. These are the most popular and more often founded in the organizations. On the other hand, every framework require certain adaptation during the implementation process to fit the organizational needs and it could even be argued whether 'generic' frameworks actually exist (Andy Neely et al., 2005). In the following pages a thorough review of the literature will show some of the alternative frameworks and key performance indicators outlined by the academia attending specific needs depending on the industry, environment, stakeholder position or project phases focus.

Frameworks

The academia has developed a number of performance measurement frameworks in a variety of forms. Although some of them are derived from the Balanced Scorecard or the EFQM Excellence Model, there are some frameworks that are independent of these models. Another difference can be made between generic and industry specific frameworks, being the latest more common. This can be an attempt from the academia to make general frameworks easier to understand or attending specific needs. The extension of the frameworks it also fluctuates, acknowledging the challenge of developing specific key performance indicators valid for a wide range of organizations, unless the purpose of the framework is narrowed. Following are presented some of the frameworks found in the literature, making special emphasis on those related to the construction industry.

Kagioglou et al. (2001) presented a generic measurement framework based on the Balanced Scorecard adding two perspectives, project and supplier. This framework is represented by the input (the strategy), process (the deployment of the strategy according to the BSC perspective plus project and supplier) and output (the metric or result of the measurement) of the performance management process.

Other relevant framework is the performance prism created by A. Neely et al. (2002). It is a generic framework integrated by five perspectives comprising stakeholder satisfaction, stakeholder contribution, strategies, processes and capabilities. The system consider four fundamental processes for its deployment: design (concerned with what and

how to measure), plan and build, implement and operate, and refresh to remain relevant for the organization.

Beatham, Chimay, Tony, and Ian (2005) explain the implementation process of an integrated business improvement system. The authors deploy an implementation framework making use of the most common frameworks presented in the previous chapter and KPIs developed by leading organizations. The conclusions drawn emphasizes the use of the EFQM Excellence Model while pointing specific issues to ensure the successful implementation.

H. Bassioni, Price, and Hassan (2004) created a measurement framework for internal management purposes. They identified a number of gaps from previous models including the interaction between new performance measurement frameworks and existing systems and the difficulties adopting target- and standard-settings of measures. Limited research was found on validity of aggregation methods and change management as part of the implementation process. Moreover, obsolete measures are rarely detected due to static performance measurements systems and it was also identified the need of transforming the measurement system into management system.

Additionally, the construction industry would need to face specific gaps such as the limited research on learning from previous implementation processes and the measurement of soft issues. They also claimed that the design of measures specific to construction industry had not been well addressed and further research was also needed on measuring the strategy deployment. With the objective to address these gaps, a theoretical framework is presented and tested in H. A. Bassioni et al. (2005). Similarly to the EFQM Model, the management of driving factors and the achievement of performance results are the two main processes underlying the framework. Specific criteria for this Construction Excellence Model can be found in H. Bassioni, Hassan, and Price (2008) as will be presented below.

Cheung, Suen, and Cheung (2004) considered a framework based on eight critical categories of performance including people, cost, time, quality, safety and health, environment, client satisfaction and communication. They emphasized the use of web tools to develop a database system facilitating the data collection and access to

information processes. For this framework they considered a number of KPIs based on consultancy and official reports on construction KPIs. Similarly, Yeung, Chan, and Chan (2009) developed a computerized performance measurement system, although they focused on benchmarking projects based on seven weighted KPIs.

Other authors have developed specific frameworks to attend relevant aspect of the construction industry. Wegelius-Lehtonen (2001) introduced a two-dimensional framework for measuring construction logistics. The measures were grouped in improvement measures, which aimed to find out the present logistical performance level, and monitoring measures, used to screen and control the operations. The framework classify the measures based on two factors: the use of the measure according to the mentioned improvement or monitoring purpose; and the focus of measure at different levels of the organization distinguishing between company or project level and specific subcontract or material.

Other developed frameworks were focused on the design process. Kristensen et al. (2013) created a complete framework for measuring performance in the design phase of construction projects. This framework include specific indicators to be used, explaining the importance of the measure and how and when should be measured, and a proposal for the reporting method using scoreboards.

These frameworks address the question of how the key performance indicators should be elaborated, or which areas should focus on. However, not all of them include a set of specific indicators to measure. This aspect will be covered next to provide a complete overview of the performance measurement literature.

Indicators

Several authors have developed frameworks and methodologies in order to define suitable indicators in several industries (Andy Neely, Richards, Mills, Platts, & Bourne, 1997; Thor, 2008; Vernadat, Shah, Etienne, & Siadat, 2013) while others have preferred not to focus in any particular industry creating generic frameworks (A. Neely et al., 2002; Andy Neely, Adams, & Crowe, 2001). Although some of the models presented previously do not include the KPIs to be used, it can be found in the literature many other authors that have cover this issue trying to look for appropriate indicators in the construction industry.

For some of the frameworks and KPIs proposed in the literature, an as sometimes also happens in practice, the portfolio of indicators is much extended. This fact does not allow organizations to focus on the most important areas, and a selection process of metrics is needed based on active listening and understanding of the customers (J. Hauser & Katz, 1998). J. Hauser and Katz (1998) pointed the common mistakes when designing metrics (Table 2) and they suggested a seven-step system to design effective lean metrics.

Table 2: Seven pitfalls that lead to counter-productive metrics (adapted fromJ. Hauser & Katz, 1998)

Pitfalls leading to counter-productive metrics	
Delaying rewards	Rewards will be undervalued if they occur too far in the future
Using risky rewards	Uncertain outcomes beyond manager/employee control encourage short-term orientation
Metrics hard to control	Or to what extent is the metric result attributable to the team/unit being measured
Losing sight of the goal	can result in over-engineered products or misaligned decisions
Precisely wrong metrics	Measuring with great accuracy does not necessarily lead to satisfied customers
Assuming employees have no options	The goal of the metric should be making employees work smarter rather than work harder
Thinking narrowly	Consider the final goal of the metric. Anticipate solutions vs. solving problems

After investigating the most common indicators used in the construction industry, Cox, Issa, and Ahrens (2003) found six of them as the most useful according to every segment included in the study, although all of them are quantitative. This reflects the traditional culture of measuring, which only includes quantitative measures on the 'iron triangle' with the enforced exception of safety.

One of the fundamental characteristics of performance measurement models is to what extent the creative process of creating indicators is facilitated. When comparing the two most popular frameworks (Balanced Scorecard and EFQM Excellence Model), in terms of determining and monitoring indicators, the EFQM Model is found less difficult than Balanced Scorecard (H. Bassioni et al., 2008). On the contrary, Beatham et al. (2005)

claim that all business management teams in their study were familiar with the Balanced Scorecard, and they expressed that less understanding was required to use BSC effectively compared to the Excellence Model. This contradiction emphasized the uniqueness of organizational needs, hence the purpose-specific requirements of performance indicators.

Beatham et al. (2004) performed an excellent review of KPIs used in the construction industry collecting information from the most relevant organizations in the UK, as for example the Construction Best Practices Program (CBPP), the Association of Consulting Engineers (ACE) or the Construction Industry Research and Information Association (CIRIA) among many others. Also in the construction industry, H. Bassioni et al. (2008) evaluates the criteria and sub-criteria of a Construction Excellence Model based on EFQM and concludes with a set of weighted criteria.

Chan and Chan (2004) reviewed the success factors in construction projects and concluded with a set of KPIs for assessing success. They divided the measures between objective, including those related to time, cost or safety and environment rates, and subjective, such as quality, functionality or different stakeholders' satisfaction.

Other attempts of finding the right KPIs in construction provide specific tools to collect data and reporting possibilities by using computerized systems. Among them, Yeung et al. (2009) and Cheung et al. (2004) developed different systems including a specific set of indicators to monitor, control and benchmark construction projects.

In some cases, there has been identified the need of developing measurement models for specific purposes or focused in certain phases of the project. Some examples can be found in Wegelius-Lehtonen (2001), who focused on supply chain performance in construction projects, or Kristensen et al. (2013), whose performance system is centred on the design phase.

In order to facilitate the comparison among the frameworks proposed by the academia, I have developed a table where the different attributes of models are presented (see Table 3). I have classified the overview based on the authors and the framework in which they are based (indicating 'other' when they have developed their own framework), the

industry where they are focused on, and whether they are addressing any particular purpose. In the table I describe what it can be found in their frameworks, differentiating if they specify perspectives to cover when finding the indicators, criteria to be taken into account or providing the indicators to be used.

One of issues that I have detected is the large amount of indicators that comprises some of the frameworks reviewed. In this regard, there have been also some attempts in finding an appropriate method for aggregating indicators (Lauras, Marques, & Gourc, 2010). This kind of initiatives follows the direction pointed by other authors, who had claimed that more research was needed in this area (H. Bassioni et al., 2004).

As it can be observed from the number of indicators proposed, developing the right indicators is not an easy task. Although the ones showed in this section can serve as inspiration, unless the framework is very specific in its purpose cannot provide a complete set of indicators appropriate for every organization. Another source for developing sound indicators are the project's success factors.

Success Factors in Projects

In the way to look for the most appropriate indicators to anticipate the success of a project in the construction industry, it worth to look at the literature that has been discussing projects' success factors for more than three decades. My aim is to review the evolution of the success perspectives over time that could provide trends over time and reveal what aspects are the most relevant in current construction projects.

In Table 4 I show a complete review of the main concepts developed in the success factors' literature. By elaborating this table, I have identified the main trends during the last decades in the search of project success factors from the academia. The findings can help to evaluate the significance of implementing a purpose-specific performance measurement system and support the generation of relevant indicators.

Table 3: Overview of performance indicators

Authors	**Neely et al. (2001)**	**CBPP, The Egan report (targets)**	**Association of Construction Engineers (ACE)**	**Respect for People**	**Construction Industry Research and Information Association (CIRIA)**	**MCG Benchmarking Club**	**Design Quality Indicator (DQI)**
Framework	Performance Prism	KPI	KPI	KPI	KPI	KPI	KPI
Industry	Generic	Construction	Construction	Construction	Construction	Construction	Construction
Orientation	Stakeholders	Generic	Generic	Employees	Design	Generic	Product value
Type	Perspectives	Indicators	Perspectives	Indicators	Criteria	KPIs	Perspectives
Criteria/ Indicators	Stakeholder satisfaction Stakeholder contribution Strategies Processes Capabilities	*Headline:* Client satisfaction - product - service Defects Predictability - cost - time Profitability Productivity Safety Construction cost Construction time *Operational and diagnostic indicators can be found in* (DETR, 2000)	Client satisfaction - product - service Defects Predictability - cost - time Profitability Productivity Safety Construction cost Construction time Client satisfaction - overall perf Value for money Quality Time delivery Health and safety awareness Training Productivity Profitability	Employee satisfaction Staff turnover Sickness absence Safety Investors in people Working hours Pay Training Diversity Travelling time	Understanding client needs Design process Integration of design with SC Internal cost/time management Risk Re-use of design experience Innovation Client/user satisfaction	Mobilisation period Extension of time index Predictability - start on site - construction time - time - practical completion - construction costs Final account index Certificate of making good defects Change orders - co value/weeks to date - co value/contract cost No. snags at practical completion No. defects during defects liability period Accident frequent ratio	Build quality Functionality Impact

Table 3 (cont.): Overview of performance indicators

Authors	**H. Bassioni, Hassan, and Price (2008)**	**Cheung, Suen, and Cheung (2004)**	**Yeung, Chan, and Chan (2009)**	**Kristensen et al. (2013)**	**Chan and Chan (2004)**	**Cox, Issa, and Ahrens (2003)**	**Wegelius-Lehtonen (2001)**
Framework	EFQM	Other	Other	Other	KPI	KPI	Other
Industry	Construction	Construction	Construction	Construction	Construction	Construction	Construction
Orientation	Contractors	Web-based	Web-based	Design	Generic	Generic	Supply Chain
Type	Criteria	Perspectives + indicators	KPIs	Indicators + measure + report	KPIs	KPIs	Criteria
Criteria/ Indicators	Leadership Customer focus Other stakeholder focus Information and analysis Strategic mngmt. Intellectual capital management People mngmt Partnership and supplier mngmt Resource mngmt Risk mngmt Process mngmt Work culture Project perf Organizational performance Internal stakeholder performance External stakeholder performance	People Cost Time Quality Safety and health Environment Client satisfaction Communication *Specific indicators can be found in* (Cheung et al., 2004)	Time performance Cost performance Management commitment Quality performance Trust and respect Effective communication Innovation and improvement	Punctuality participation PPC RFI (request for information) Proofing Time consumption Successful alternatives Changes in brief Completeness and conformity Total cost Client satisfaction Collaboration Environment management *How to measure and report suggestions can be found in* (Kristensen et al., 2013)	Construction time Speed of construction Time variation Unit cost Percentage net variation over final cost Net present value Accident rate Environment Impact Assessment (EIA) scores Quality Functionality End-user's satisfaction Client's satisfaction Design team's satisfaction Construction team's satisfaction	Units/MH – number of completed units per individual man-hour of work $/Unit – dollar value associated with each completed unit Safety Total cost On-time completion Quality control/rework	Activity and cost analysis (ABA) Accuracy and delivery time analysis (TBA)

The first attempts looking for the projects' success factors prior to and during the '80s were, with some exceptions, vague and lacked extensive data collection although their approach was to find success factors applicable to all projects (Baker, Fisher, & Murphy, 1974; Pinto & Covin, 1989). Their main findings consisted on a complete set of success factors and their evolution along the project phases.

A group of researchers developed during the '90s a multidimensional model to assess project success. During this period, they switched from looking for universal to project-specific success factors (Dvir, Lipovetsky, Shenhar, & Tishler, 1998; A. Shenhar, Levy, & Dvir, 1997). The dimensions considered were efficiency, impact on the customer, business success and prepare for the future, having a list of success factors within each dimension. These elements were popularized under 'one size does not fit all' approach (Aaron J. Shenhar, 2001) and other frameworks assessing success as a function of the technological uncertainty and complexity of the project (Aaron J. Shenhar, Dvir, Levy, & Maltz, 2001).

From the 2000s increased the emphasis on the projects' influence on business success and how they contribute to adapt to a changing environment (Abraham & Chinowsky, 2003; Udechukwu, Johansen, & Greenwood, 2008). At this time were introduced industry-specific frameworks attending the call for project-specific approaches. Chan, Scott, and Chan (2004) included external environment factors in the framework for the construction industry, and other authors researched success factors of specific stakeholders such contractors of subcontractors (Al-Tmeemy, Abdul-Rahman, & Harun, 2011; Ng, Tang, & Palaneeswaran, 2009; Schaufelberger, 2003).

In recent years, the focus has been in the human factors affecting the success of the projects, keeping the focus on specific industries when developing success models (Elattar, 2009; Tabish & Jha, 2012). The current trend emphasizes the importance of the project participants' experience and the interrelation among the success factors for the different stakeholders (Alzahrani & Emsley, 2013; Gudiene, Banaitis, & Banaitiene, 2013; Inayat, Melhem, & Esmaeily, 2015).

The review of these success factors does not provide any group of indicators that should be applied in construction projects but it does point three areas of reference when finding

these indicators. The first area is related to human factors in project success, which include groups such management and employees. The second area of interest is how projects contribute to business success and the market perspective on project success, which includes a strategic point of view. Finally, the inclusion of external factors to project success and therefore pointing the need of measuring these aspects.

Table 4: Evolution of projects' success factors in the literature

Author	Year	Findings/Conclusions
(Baker et al.)	1974	**Holistic approach** to project success containing numerous variables. Include external factors where little or no control from management is possible, affecting success through the environment.
(Pinto & Covin)	1989	There are some basic similarities (academic perspective) and characteristic differences (practitioners' perspective) between SF. The importance of the SF change dramatically at different **stages** of the project.
(A. Shenhar et al.)	1997	**Multidimensional universal** framework to assess project success. Efficiency, impact on customer, business success, prepare for the future are the four dimensions of SF.
(Dvir et al.)	1998	Project SF are not universal for all projects. Multidimensional perspective. Managers should identify **CSF to their specific projects**. Design considerations are found generally relevant.
(Aaron J. Shenhar et al.)	2001	Multidimensional **strategic** framework considering different **timeframes**. Relative importance of success dimensions according to **project type** (technological uncertainty).
(Aaron J. Shenhar)	2001	**One size does not fit all** approach to project success. Different project should be managed differently. SF depend on technological uncertainty and **complexity** (scope).
(Aaron J Shenhar, Tishler, Dvir, Lipovetsky, & Lechler)	2002	Project success influenced by a wide spectrum of variables.

		Multivariable model able to account for **interactions among SF**
(Abraham & Chinowsky)	2003	**Construction-specific** SF. From project success (completion) to business success (ability to adapt in changing markets).
(Schaufelberger)	2003	**Contractor perspective** of SF. Relation with project owner, defined scope and allowing design innovations.
(Chan et al.)	2004	Framework: groups of **independent variables**, including procurement, human factors and **external environment**.
(Udechukwu et al.)	2008	Project influence on **business success**.
(Elattar)	2009	Stakeholders' perspective on project success. Hierarchical framework including external and teamwork factors.
(Ng et al.)	2009	**Subcontractors' perspective** on project success, focused on equipment-intensive companies.
(Al-Tmeemy et al.)	2011	**Contractor perspective** of project success towards business success. Three areas of assessment: project management, **market** and product.
(Tabish & Jha)	2012	**Human factors** play a decisive role in project success.
(Müller & Jugdev)	2012	Historical review of success factors. Project success is a multi-dimensional and **networked interaction** of personal, project team and organizational success.
(Gudiene et al.)	2013	71 success factors grouped in 7 areas including human related factors, competence and **experience**, being the latter identified as the most important SF.
(Alzahrani & Emsley)	2013	Contractors' perspective, grouped in 9 clusters: **experience**, past performance and environment among others.
(Alsulamy, Gupta, & Sloan)	2014	Construction industry, SF depending on project phase including **maintenance** phase.
(Inayat et al.)	2015	Construction industry, stakeholders' perspective on success. Success factors are **correlated among stakeholders**.

Organizational change

The last part of the literature review is dedicated to organizational change processes as part of the implementation of new methodologies. It is especially relevant to cover this issue given that this thesis concerns two aspects with significant implementation challenges, performance measurement and Lean construction.

Both performance measurement systems and lean construction point to the failure to initiate change as one of the causes for unsuccessful implementation (G. Ballard, Kim, Jang, & Liu, 2007; Beatham et al., 2004). The change process of practices within the organization should be should be managed accordingly to avoid internal resistance leading to failure of the new methodologies before being implemented. As Robinson et al. (2005, p. 17) claimed, '*people and organisations often find change difficult and there is sometimes resistance to adopting new ways of doing business*.' Acknowledging the current culture in the construction environment can contribute to a smoother change process (Cheung et al., 2011)

Implementation process

The implementation process of performance measurements systems have some different factors compared with Lean construction despite of some commonalities. One of the biggest threats for a performance measurement system is to be perceived by employees as a blame allocation tool. Employees feeling the measures as a way of controlling who is doing his/her work from management is the first step to failure (Andersen & Fagerhaug, 2002; Beatham et al., 2005). Another important barrier in the implementation of measurement systems is the required ability to determine and monitor indicators (Robinson et al., 2005) with the additional need of having the appropriate infrastructure to capture and distribute the results (Beatham et al., 2005). Linked to the infrastructure is the lack of data and the resources needed to develop the system in terms of time and costs (Robinson et al., 2005). The last barrier identified is the actual use of the system and whether it support the decision making process or the measures do not have any effect in the organization (Beatham et al., 2005).

Managing change to overcome the resistance within the organization and the role of knowledge management are some of the key considerations in the implementation

process. Other aspects supporting the successful implementation are choosing SMART measures (Specific, Measurable, Attainable, Relevant, Timely), understanding the purpose of measurement and the system reflecting the way organization operates (Robinson et al., 2005).

Establishing a performance evaluation system can be part of the strategy for the success implementation of Lean practices (Bakås et al., 2011). The challenges in the Lean construction implementation do not come only from the adaptation of Lean to a project based setting, but implementing Lean has some challenges itself.

The sustainable implementation of Lean should reach four levels according to Dombrowski and Mielke (2014). The first level is Lean as a philosophy, adopting a long-term thinking of these practices. The second level is Lean processes, which is commonly defined as eliminating waste. The third level refers to people and partners, who should be respected and challenged in order to encourage their growth. The last level is problem solving, explained as a learning process from failures and breakdowns.

Other authors highlight the success factors of implementing Lean under specific groups in the industries, which can be also relevant to the construction industry. Powell et al. (2014) established a new set of principles for engineer-to-order production systems, which can be directly related to the construction industry, and Bakås et al. (2011) named six critical success factors for the Lean implementation of small and medium companies as most of the subcontractors in the construction industry.

There are in the literature a number of authors addressing the challenges in Lean Construction implementation. The most extended description of this process is probably given in G. Ballard et al. (2007). There are two aspects of organizational change mentioned in the report that can be highlighted. First, the ‘learn by doing’ approach to explain that change in practice can change thinking. This encourages the use of demonstration projects and celebrating early wins to maintain momentum. The second conclusion to highlight is the way to change the company culture by changing management practice. This can be done through structured evaluations and rewards, encouraging thoughtful experimentation and challenging previous best practices. Other aspects stressed in the literature is the need of a bottom-up approach for a successful

change management (Arayici et al., 2011) and the joyful learning process which should include practice-focused training and involve subcontractors (Kim & Park, 2006; Salem, Solomon, Genaidy, & Minkarah, 2006).

The common factors found in the implementation process of Lean and performance measurement systems are the commitment and support from the management and the involvement of employees, either when creating indicators or developing Lean practices through their participation (Andersen & Fagerhaug, 2002; Bakås et al., 2011; G. Ballard et al., 2007; Beatham et al., 2005; Robinson et al., 2005).

The analysis of barriers and success factors in the implementation process of both methodologies is relevant when designing a new model. It is difficult to find the utility of a model that will hardly be implemented, thus implementation issues should be carefully considered.

The Ladder of Inference

It has been already mentioned the critical role of knowledge management when implementing new methodologies. For this reason, it is relevant to not only mention its importance but also include a model that can explain in a simple and clear way what it does involve.

Senge (2014) built in systems thinking theory a mental model to explain how people rationale their behaviour changes. Figure 7 shows this model, which explains the process of change based on observable 'data' and experiences. This can refer to previous work or practical training in case of new work methods. From the data observed and experiences, the individual selects a certain part of it that will be further processed. The next step in the ladder is to add meaning to the data selected based on cultural and personal background. Individuals with work experience from different fields would have different understanding on the same information provided, for example if explaining Lean principles to a construction site manager and a production plant manager.

As individuals add meaning, they also make assumptions based on their understanding of the information and draw their own conclusions. Based on these conclusions, they adopt beliefs about the world that will also influence the data selection from what they observe.

The phenomena of affecting data collection from the individual's beliefs is what Senge called the reflexive loop. The reflexive loop could explain partly the resistance to change, since the individuals' experience would facilitate that individuals tend to look for data that reinforces their beliefs. The last step is to take actions based on their own beliefs (Senge, 2014).

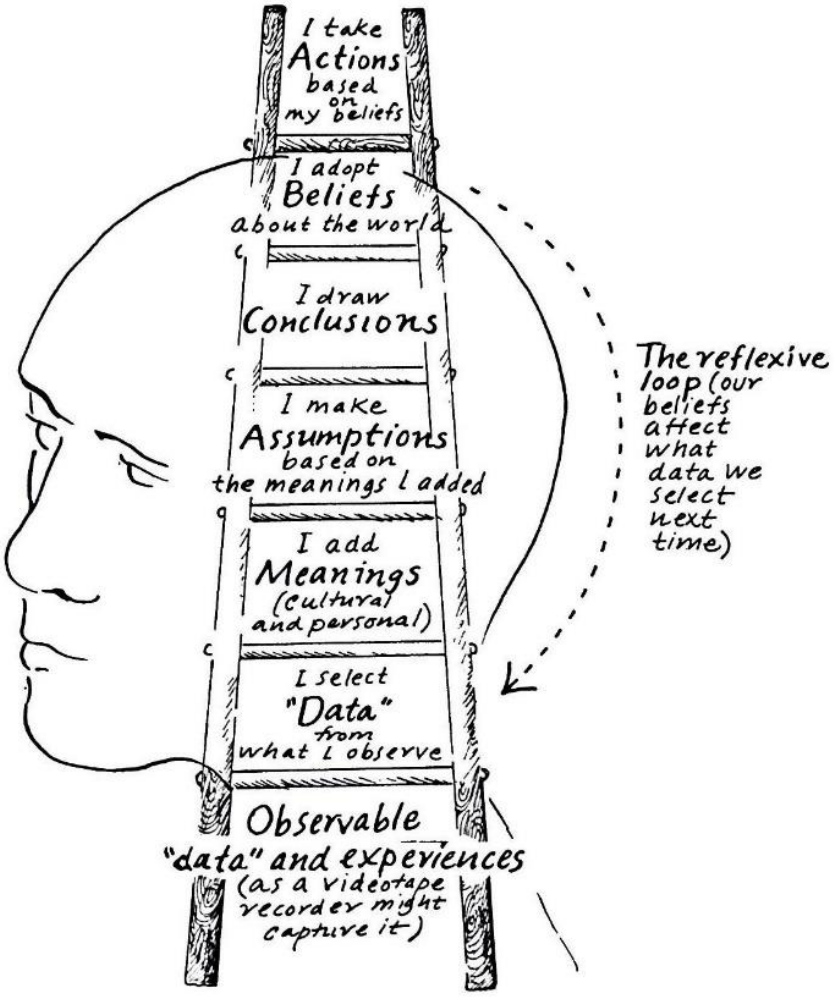

Figure 7: The Ladder of Inference mental model (Senge, 2014, p. 243)

Explained from a practical perspective, let us assume that construction workers are receiving a course in Lean practices. Considering a practical course where workers test on physical pieces the practices to be implemented, workers would observe how the new methods work. Assuming the vast amount of information that can be collected, they would select what is most relevant, being affected by their current beliefs, and add meaning based on their experience in actual construction work. Once the data obtained from the course has been added meaning, the worker would make assumptions, for

example assessing requirements for the applicability of the practices, and then draw some conclusions about practices' effectiveness. If the worker has concluded positively about the use of new practices, s/he will adopt beliefs and take action accordingly.

The present model is just an example of how organizational change can be facilitated from individuals' perspective. This kind of models can also help to associate some of the concepts emerging the implementation literature such as workers motivation, competence, construction industry culture and learning processes.

Summary of the chapter

A literature review on frameworks and indicators presented by the academia is examined in the first part of the chapter. It has been found from generic frameworks that take Balanced Scorecard or EFQM as a reference to then adapt them into specific context. Other authors create independent frameworks to address identified needs, and often are adapted to settings such as the construction industry, environment, stakeholder position or project phases. I developed a detailed overview of indicators in Table 3 classifying the frameworks developed by the academia according to their industry focus, specific orientation within the system and the basic classification of indicators.

Additionally, the overview of indicators is strengthen with the study of projects' success factors. The literature review on this topic that I developed in Table 4 through a chronological overview shows a clear evolution from holistic approaches towards '*one size does not fit all'* approaches. Furthermore, construction and stakeholders-specific success factors studies emphasize their interrelation and the importance of human factors. This reinforces the creation of purpose-specific frameworks and the inclusion of a variety of effects affecting the success of projects.

Finally, the challenges of organizational change are covered by having a closer look at the implementation process. Some challenges in the implementation of performance measurement systems is to handle the measurement culture so it is not perceived as a blame allocation tool, the ability to create a monitor the indicators and the lack of adequate infrastructure to capture and distribute the results in order to serve as a decision making tool. On the Lean construction side, its implementation requires an organizational

learning effort that should encourage practice as learning method and the use of structured evaluations and rewards. The Ladder of Inference is purposed as a model for illustrating the culture and organizational change through the reflexive loop supported by practical training.

Chapter 5:

Methodology

The purpose of this chapter is to provide a detailed description of the process followed along the thesis, from choosing the topic to analysis of results, and indicate the research theories that support the methodology followed. The steps that lead to the findings will be outlined according to relevant research literature. In this regard, I will describe the choices taken during the development of the thesis and explain how they affect the results obtained.

Purpose of the project

The first step in the development of this report was to define the purpose of the project by being aware of the overall purpose and the specific learning outcomes, as well as establishing the basic boundaries that frame the project (Polonsky, 2001). This study conforms the Master Thesis required for completing the Master in Project Management under the specialization of Production and Quality Engineering at NTNU. The thesis is simultaneously carried out under the SpeedUp project at SINTEF, whose main objective is to develop strategic, tactical and operational measures in order to reduce overall execution time in complex construction projects by 30-50%. This context delimit the boundaries of the project, establishing a time frame of 20 weeks for its completion.

Exploring and defining the topic

Once the purpose of the project was acknowledged, I explored a number of topics that could be relevant for the project. After previous studies comparing performance improvement practices in different industries (Limon, 2014), this was clearly one of my areas of interest. On the other hand, performance measurement was also a topic in which I was interested from subjects during my education, and conversations with academic members of the project revealed some current initiatives from the industry in this topic (Langlo et al., 2015). As a result of these aspects, the topic that I proposed was to relate performance measurement to improvement practices in order to facilitate their use from the industry.

After some time exploring these topics with other members of the project, professors at the University, reviewing academic journals and other references I had an overall perception of the relevance of the topic. Polonsky (2001) cited some issues that need to be considered in this regard. As mentioned, my own and the thesis stakeholders' interest was checked and I also found the topic appropriate for the purpose. The major problem that I experienced at this stage was that because of being a topic with very recent interest, I had some difficulties finding a great amount of literature that address the conjunction of both topics. However, given that both topics were well covered separately I took it as a challenge to overcome in the thesis. The decision of covering both topics forced me to focus on the advances of the topics in the context of construction industry, limiting the their extension in other areas and industries. Despite of later small adjustments on the topic would arrive, the main idea of the thesis was defined after the first meeting of the project. At this meeting, every participant shared what would be their focus areas and possible projects for data collection.

The final definition and perspective of the topic would come after further discussion with other researchers at SINTEF with expertise both in Lean and performance measurement and some contacts with the industry trying to find sources of relevant data. During this stage I had some difficulties in getting data from projects about performance measurement and improvement practices due to the scarce measurement culture. As a result, I decided to adopt a perspective in which performance improvement practices at the industry was the start point, adding extensive measurement literature review to

produce the results. From the discussion with the researchers I also learnt that would be more interesting to focus on the effects of implementing Lean rather than the implementation itself. With this decision I limited the approach to be taken for each topic, avoiding extensive literature review on Lean Construction practices. Although a limitation, obtaining data about Lean mostly from the industry could reflect the exact situation of the context without being influenced by external conditions in different contexts. As well, I limited the scope of the topic to benefits and drawbacks observed when implementing Lean and maintaining out of the scope the detailed step-by-step process of implementing Lean.

As a result of these limitations, I adopted two different approaches in the literature review depending on the areas covered. While Lean literature presents an overview of the principles and practices as a foundation for the data observed in practice, performance measurement required a deeper insight into the literature in order to build the results. The literature review of performance measurement frameworks is completed in two steps. First, I provide a detailed overview of the most common models, for which I preferred the use of books explaining the concepts, implementation and use in practice. Second, I performed a thorough scrutiny of articles and conference proceedings to examine specific adaptations of models, use of indicators, success factors and implementation issues. I reflect this difference in the creation of two different theory chapters about performance measurement.

Research questions and classification

Based on the decisions made during the exploration of the topic and given the limitations that I have established previously, I defined a set of specific research questions to frame the study. Although the main research question is the last one, I decided to elaborate three introductory questions to guide the logic of the study, serving as fundamental inputs for the final goal of the thesis. These are the research questions:

1. What performance improvement attempts are construction companies carrying on?

2. What are the effects of these practices in project performance?

3. What are the stakeholders' needs in the implementation process?

4. How can these effects be measured (in order to support the fully implementation of those practices)?

The application of the present research is intended to produce an improved understanding of the effects of implementing performance improvement practices and the possible application of performance measurement systems in this context. According to Kumar (2005), this would lead to classify the study as applied research attending to the application perspective.

Research can be classified from the perspective of its objectives as descriptive, correlational, explanatory or exploratory (Kumar, 2005). According to these questions, the objectives of the research can be divided in two steps. Questions 1 to 3 are attempts to describe the phenomenon of implementing performance improvement practices in the Norwegian construction industry, so they are classified as descriptive research. However, the last question is trying to investigate possibilities connecting two concepts that have not been often covered together before (performance improvement practices and performance measurement). For this reason, question 4 is classified as exploratory research.

The last possible classification described by Kumar (2005) is from the perspective of the inquiry mode. The unstructured approach is claimed as more appropriate to explore the nature of the phenomenon rather than determining its extent, which would correspond to a more structured approach (Kumar, 2005). The purpose of the study is to describe the implementation of performance improvement practices and establish the variation through its effects without quantifying them, which is identified as qualitative research.

Besides Kumar's classification of research, I have differentiated between two possible paradigms to define my approach in this thesis. These paradigms are described in Ekambaram (2008). The positivist paradigm considers that there is one single reality, and that the reality is objective. This imply that the researcher can study a phenomenon without having influence on it and his/her opinion will not affect the observation. Derived from this paradigm, post-positivism maintain the view of only one objective reality

although it assumes that the reality is so complex that it is not possible to be completely understood. Quantitative research is usually the methodology used under this paradigm.

The second paradigm described in Ekambaram (2008) is the interpretive paradigm. This paradigm is characterized by the belief of multiple, constructed realities in which the observer's opinion influences the study of the phenomenon. Therefore this paradigm uses methods aimed to understand the phenomenon with an emphasis on contextual elements such as human and organizational behaviours. Interpretivism accepts the difficulty in creating an objective understanding due to the possibilities for alteration in the iterative process.

From the two paradigms, I have chosen the interpretive paradigm for this thesis. Hence I will look at how respondents comprehend their experiences in the implementation process of performance improvement practices. Based on this decision, the methodology indicated for this paradigm is qualitative research.

Qualitative methodology and methods

From the methodologies outlined by Petty, Thomson, and Stew (2012) within the qualitative research, the present study is inspired in the *grounded theory* although it can be found traces from phenomenology and other methodologies. This methodology consist of generating a theory that explains a social process constructed from the participants who have experienced the phenomenon.

This methodology can adopt two approaches: emergence of concepts from the data or the theory being constructed by the researcher. In this case both approaches might be observed. On one side, descriptive research can be associated with the emergence of concepts from the data, while exploratory research is aligned with the idea of a theory being constructed by the author.

I selected the participants in the study according to theoretical sampling method, although it cannot be denied certain degree of purposive, convenience or snowball methods (Petty et al., 2012). It may be argued that the sample was selected on basis of analytical insights, since interviewees were directly involved in the early phases of implementing performance improvement practices at their respective companies. However, it must be

acknowledged the difficulty in getting in contact with relevant actors who had a positive disposition towards both topics covered, especially regarding performance measurement in construction projects. Therefore I also adopted the purposive method, involving participants according to relevance to study. At the same time, I used the snowball method when asking contact persons and potential participants to nominate other relevant candidates. Another particular method out of the ones mentioned that I used when looking for participants is the collaboration with other students with similar areas of interest.

An initial set of four interviewees accepted to participate in the study. Although it might be argued the reduced number of interviews, a broad range of stakeholders in construction projects and at different levels of management was represented. This could provide enough degree of significance. Given that the requisites for a meaningful analysis was covered with a minimum number of interviewees from a wide spectrum of the industry, and the difficulty in finding more relevant actors, the convenience method was also adopted (although the selected participants were selected according to hardship rather than ease reasons). In Table 5 I present the profiles of the participants in the interviews anonymized to preserve their identity according to the document registered at the Norwegian data protection office.

Table 5: Anonymized presentation of the interviewees

Data collection interviews	
Interview 1	region manager of the construction business area at one of the biggest contractors in Norway, with an experience of more than 20 in the position and large experience implementing Lean practices. The company has also presence in other industrial areas and business units in different countries.
Interview 2	VDC manager and structure engineer with over 3 years in the position responsible for the implementation of new methodologies regarding the design. The company is a very relevant contractor national wide and it has also presence internationally as well as in other industrial areas.
Interview 3	project manager at a state owned company meaning that their role is the project owner. The interviewee experience with Lean is quite

	recent although he/she has managed a few small but rather complex projects in their execution requirements, although the company has more experience applying Lean in previous projects.
Interview 4	regional operations manager with high involvement in the planning phase of projects. He/she has been in the position for more than 7 years and he/she participates in the implementation of Lean practices. Although from a different region, he/she is employed by the same company as Interview 2.
Results evaluation interviews	
Interview 5	researcher specialized in Lean manufacturing and performance measurement systems. He/she has two years' work experience as project manager from an international technology company and he/she has participated in multiple research projects. He/she was also interviewed at the definition stage of the thesis.
Interview 6	researcher with recognised experience in the development of performance measurement systems. He/she has also published about the effects of Lean in the construction environment.
Interview 7	researcher and project manager in construction related research projects. Uncertainty management, success measurement and project planning are the research areas from some of his/her publications.
Interview 8	double interview with the project manager and the site manager from the contractor company. The project manager had experienced the implementation process of Lean practices within the company while the site manager entered the company when the practices were already in use. Thus both have several years' experience running projects under Lean practices. They are part of the same company as the Interview 1.

The resulting sample used for the data collection covered contractors and owners, from design to execution and from region managers to engineers. In order to reinforce the data collection, more interviews with experts in Lean and performance measurement and large experience in research projects within the construction industry were performed to confront the results. Furthermore, the model was presented to the research project

manager and to practitioners in a final interview with a project manager and a site manager to assess its validity, utility and reliability. This settles the final set of interviews in eight, four for the data collection and another four for evaluating results.

The data collection was based on a number of semi-structured interviews. They involved pre-determined areas of interest for the case. The first part of the interview covered general aspects presenting the profile and experience of the interviewees and their role within the company. Then interviewees were inquired about their experience with performance improvement practices and their development process in the company, including a stakeholder perspective table. The third area covered was the benefits obtained from implementing these practices, followed by the barriers and success factors experienced. The next step was asking about current project performance metrics and evaluation methods. Finally, interviewees had to rank their preferences about the characteristics of a hypothetical measurement system. The interview guide used to structure the interviews can be consulted in the Appendix C.

Although several examples were provided along the interviews, the interview guide did not considered specific projects or type of projects. This allowed having a general perspective necessary for the development of a model aimed for the whole industry. On the other hand, it must be recognized the weakness of the result since is not able to consider specific barriers or benefits that can be particular to some type of projects. Given the innovation of the topic and that previous performance measurement models specific to Lean context were not found, it was preferred to adopt a general overview of the industry to build the model. In this regard, it is worth to mention the extension of the data collection interviews with an average duration over 90 minutes and carried out face-to-face, by phone and via internet, indicating the thorough review of the topic with practitioners. Most of the interviews were done in English, with the consent of all the participants, with the exception of the interview presenting the results to practitioners that was completed in Norwegian language attending their requests. All the interviews with practitioners were done in partnership with other student interested in the object of study, although each of us had the opportunity to ask questions related to our specific topics.

Petty et al. (2012) claims that grounded theory methodology involves coding data such as interview transcripts, which are used by the researcher to abstract them into broader

concepts and categories to capture the complexities. This method is based on continuous collection and comparison of the data set in an iterative process called comparative method of analysis. This is carried out until there is a theoretical sufficiency where '*relationships between abstracted codes are identified to create an explanatory model'* (Petty et al., 2012, p. 379).

In practice, the code of data was made grouping the answers according to the different topics explored due to the high degree of freedom in the structure of the interviews. This was necessary in order to facilitate the iterative comparison process in the analysis to build the results. The analysis process is showed to a great extent in Chapter 6, where the outcomes of the comparison are described and the concepts from the data emerge. Likewise, Chapter 7 provides a description of the models constructed by the author.

Validity and limitations

The research is assessed according to four criteria established by Petty et al. (2012): confirmability, dependability, credibility and transferability.

Confirmability refers to '*the extent to which the findings reflect the focus of the inquiry and not the bias of the researcher'* (Petty et al., 2012, p. 381). The author has experience from other industries where some performance improvement practices are already established, which may show a positive predisposition towards these methodologies. The lack of experience within the construction industry can be a limitation about the knowledge of the internal culture, but also an advantage for reducing bias. The limitation of lack of experience in the industry is compensated by the high degree of involvement of experience researchers and practitioners in the process through interviews and periodic presentations.

As a qualitative study, the data analysis accepts its dependability on the context, the people involved and the creative activity from the researcher (Petty et al., 2012). In this case, the context is the Norwegian construction industry, the environment of SpeedUp project at SINTEF, and the professors at NTNU involved. An audit trail of the process followed in the form of public presentation within the SpeedUp project was carried out periodically to ensure consistency. Despite of some authors consider dependability in

qualitative research as an expression of reliability (Golafshani, 2003), I will discuss this concept with greater detail later on.

The credibility of the findings is tested through peer debriefing with a researcher outside the SpeedUp project context and collecting data from different perspectives (triangulation). This includes obtaining data from different organizations, at different perspectives of the project and in a range of positions. Furthermore, the study also seeks to verify the findings with participants after completion of the report.

The extent to which findings can be applied in other contexts is assessed by its transferability. It has been already mentioned that the context of the present thesis is the Norwegian construction industry, which includes its own practices and culture. With a complete set of four interviews for the data collection with four additional interviews presenting the results, the result cannot be directly transferred to neither the rest of Norwegian construction industry nor any other field. Although other authors have found similar results about specific areas of the results, such as success factors in the implementation of Lean described by Bakås et al. (2011) in small and medium manufacture companies in Europe, it is responsibility of those who might apply the findings into their own setting to determine the transferability (Lincoln and Guba, 1985; Sandelowski, 1986; mentioned in Petty et al., 2012).

The contemporary search of reliability in qualitative research is connected with specifying the relevant context of observation (Kirk & Miller, 1986). The definition of reliability in qualitative has been largely discussed, showing opposite approaches that go from discarding relevance in qualitative research to claiming the need of being judged by its own paradigm's terms (Golafshani, 2003). Other authors link together the verification of validity and reliability assessing methodological coherence, appropriate sample, collecting and analysing data concurrently, verifying new ideas with data already collected and moving theoretical development from the perspective of data to a conceptual understanding (Morse, Barrett, Mayan, Olson, & Spiers, 2008). Most of the assessing elements under this perspective are already explained as the methodological coherence, the sampling methods, verification of new ideas and the theory development. The concurrent process of collecting and analysing data can be proven by the development of variables prior to the development of interview guide, which are included

in the document provided in Appendix C. According to Morse et al. (2008), this would ensure the reliability of the study.

Based on Golafshani (2003) understanding from the qualitative research perspective, the way of testing validity and reliability is eliminating bias and increasing the researcher's truthfulness of a proposition about some social phenomenon using triangulation. Moreover, '*triangulation may include multiple methods of data collection and data analysis, but does not suggest a fix method for all the researches'* (Golafshani, 2003, p. 604). I have considered triangulation through interviewing different stakeholders, peer-to-peer discussion with my partner on the interviews and other students involved in relevant areas of the topic, presentation of results to researchers and practitioners and comparing results from previous studies. From my point of view, this creates a reasonable foundation for accepting the reliability of the data collection and analysis.

Although the number of interviews could be considered as a limitation, the four interviews for the data collection can provide an understanding of patterns of work and behaviour in the project context. This understanding would contribute to know the characteristics of the connection between performance measurement and implementing Lean in projects. Other limitation is the generalization of the model, which could need adaptation according to the type of projects aimed to be measured. Further limitation is the capability of considering a limited amount of frameworks and theories, which might also limit the result. The criteria for the selection of frameworks was to consider those more often mentioned in performance measurement literature. Consequently, some relevant but less popular frameworks could be missed, although the timeframe of the thesis also limits the ability to cover a wider extent of literature.

Summary of the chapter

This report is written within the boundaries of the thesis for the Master in Project Management at NTNU and the SpeedUp project at Sintef. The topic was defined and found relevant after discussion with researchers, professors, PhD candidates and other staff, and the research questions were defined accordingly. The data collection is based on theoretical sampling methods comprising four interviews with practitioners from different stakeholders and at different levels of management, complemented with four

more interviews with researchers and practitioners to assess the results. This defines the thesis as qualitative research, combining emergence of concepts from data for evaluating the current use and effects of Lean construction and theory being constructed by the researcher for the generation of the performance measurement model. The validity of the study is satisfactorily evaluated under criteria of confirmability, dependability and credibility, whereas transferability should be assessed by those applying the results. Triangulation also confirms the reliability of the analysis. Other limitations are the time constraints, the capability of considering a restricted number of performance measurement frameworks and the data collection possibilities reduced to four interviews.

Chapter 6:

Lean Construction in the Norwegian Industry

In this chapter the data obtained will be presented and analysed. Through this analysis, the basic ideas of how improvement performance practices are being implemented in the Norwegian construction industry will be highlighted. I will describe the analysis in three stages according to the following structure.

First, I will explain the part of the analysis related to perception of Lean from the practitioners, introducing the data collection process, the practices observed and their view of Lean that I have reflected in a Lean Construction model. This stage also contains the implementation process of Lean as described from the interviewees and the stakeholder analysis for this process.

Secondly, I will present the part of the analysis focused on the effects of Lean and the success factors for the implementation of these practices. This is a key step to develop the performance measurement model that I will reveal in the next chapter.

Finally, the analysis from the data obtained regarding performance measurement in projects will be outlined. These aspects are important because reflect the current measurement culture within the construction industry and provides an insight on their point of view of the desired measurement system. By considering these aspects, I will be

able to develop a model better adapted to their expectations connecting Lean practices and performance measurement frameworks.

Data collection

The data was obtained through a number of interviews with representatives from some of the most relevant companies in the construction sector in Norway. Previous to the interviews with the practitioners, the interview guide was evaluated with an expert from the academia in Lean and Performance Measurement to have the most adequate and fruitful perspective on the report.

The total amount of interview for the data collection was four. This includes representatives from three different companies covering a wide range of stakeholders in the industry. Project owner and contractor as well as the design side and the construction side were represented. At the same time, different levels of management were included, from the principal responsible for design practices and operational manager to owner's project manager and region manager participated in the interviews. The wide range of stakeholders and level of management provided a set of data that even though is not very extensive, is able to represent the different perspectives minimizing the possibility of biased results.

The experience of interviewees with Lean vary depending on what practices have been used in their respective companies. Since the efforts for implementing improvement performance practices have been quite recent in most of the cases, interviewees experience is mostly in the attempt of implementing Lean. Only the company that has implemented Lean for a longer period of time has above 10 years' experience in the process. Far from being a weakness, this profile of participants strongly supports the purpose of this study, which is focused on the implementation process.

Lean practices

The practices that have been found more often applied are Last Planner (referred commonly by the companies as involving planning), Virtual Design Construction (VDC or BIM) and Pull Scheduling (backward planning). It is certain that these 'practices' are not practices as such, rather tools. Nevertheless, their use serve the purpose of Lean

principles like reducing waste in the process. The difference between practices and tools according to the Oxford Dictionary that practices are '*the customary or expected procedure of doing something'*, while tools are the *'things used to help perform a job'* (Oxford, 2015). Since these tools are main contributors to create the practice, they all will be considered as Lean practices.

Following this argument, Concurrent Engineering (CE) is also considered as practice following Lean principles. According to the interviewee working in design where is applied, '*concurrent engineering has the purpose of cutting off the waste in meetings, as Lean is about'* (Interview 2). Although the use of CE was not rooted directly from the implementation of Lean, it follows Lean principles and therefore is included as Lean practice. This argument is also validated by the expert in Lean consulted, who claimed: '*CE is particularly relevant shortening the product development timeframe'* (Interview 5). Koskela (1997) includes concurrent engineering at methodology level of 'the new production philosophy' named Lean.

The Lean model in construction

The basic understanding about the definition of Lean Construction is common among the interviewees. All of them mentioned the reduction of waste in one way or another. Reducing use of material, useless hours at the working place, lack of quality, lack of communication, improved planning or having effective meetings are some examples of the Lean characteristics cited. Other aspects of Lean mentioned were the importance of being proactive to sort issues earlier, the team spirit of building together and the trust in workers on their inputs (duration of activities).

Besides all these ideas about Lean, the model that can best describe Lean Construction was disclosed during the interviews and it is represented in Figure 8. As opposite as in manufacturing, construction industry has not the ability to move the product through the different assembly stages until is completed. Instead, are the workers who should move in a coordinated way through the construction site to perform the different activities on the product until this is completed. Similarly as in manufacturing, is important that these movements are coordinated to get the same pace along the project, which will allow adjust activities and reduce waste. In this way, the construction process is compared with the

movement of a train, so workers moves over the construction site completing the required activities. The key idea is that is not possible to move only one coach independently, but all of them should move together. Of course this model does not pretend to gather all the complexities of Lean theory, rather providing a fundamental model easy to understand by practitioners.

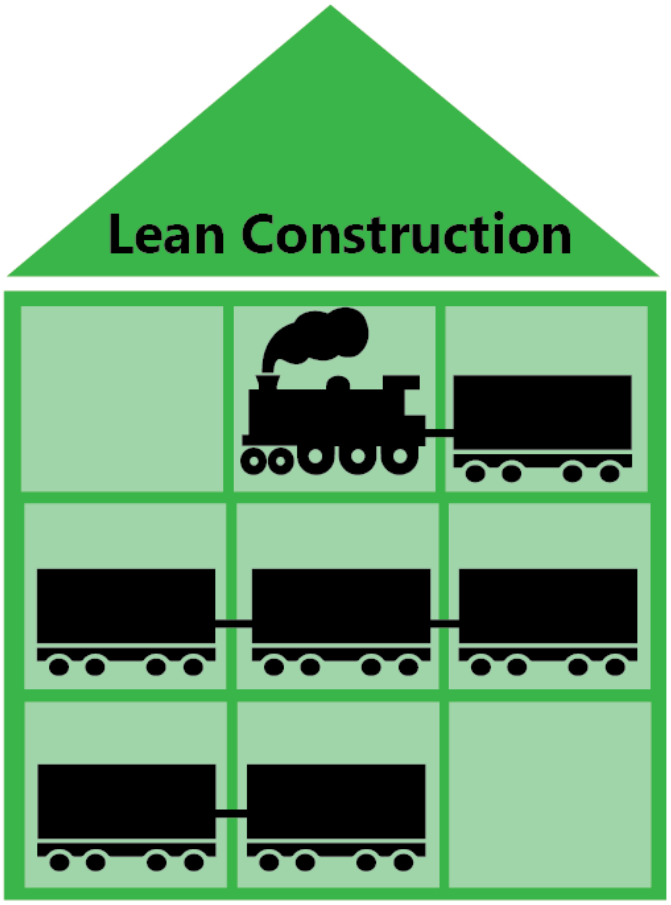

Figure 8: The Lean Construction Model

Implementation of Lean

The level of implementation varies greatly among companies. Only one of the companies have implemented Lean as the company's strategy, enforcing its implementation in every project. For them, Lean '*is not only a new method, but also a new culture that everyone in the company need to understand'* (Interview 1). Specific practices such as involving planning is often company wise implemented, while pull scheduling and concurrent engineering application has been found to be more often project-specific. In some cases, Lean practices are applied to specific parts of the project, not even to the whole project. This fact brings the question about how far is Lean implemented. Although

manufacturing academia has developed several models to assess the leanness of the production system (Vimal & Vinodh, 2012; Vinodh & Balaji, 2011; Wan & Frank Chen, 2008), this study is focused on the effects of Lean as a consequence of its implementation rather than assessing the level of leanness of companies.

The motivation for implementing Lean has often had workers at the origin. In some cases they claimed improved planning creating a bottom-up approach of the implementation. It has been also reported initiatives from management to reduce absence rate in projects. From the two approaches, the bottom-up approach has shown much more difficulties towards the change, and top-down approach has been recommended from this experience. Academia is usually involved in the implementation process, especially when the scope for its implementation was wider than a few trial projects. The results from the research on reducing absence rate in construction was to involve workers in the weekly planning improving predictability, and providing room for a better assessment of the worker about whether he/she could perform the planned tasks. This leads to one of the effects of Lean that will be further analysed below.

Actors' involvement and training

One of the critical aspects to be considered during the implementation of Lean is which actors should be involved and to what extent. Generally, all managers, workers and subcontractors must be involved to get the expected results, especially when using practices applied on site. Moreover, this issue have particular challenges when implementing Concurrent Engineering in the design phase. A project manager mentioned the importance of involving even workers from other countries participating in the project and that did not speak the local language fluently, giving an idea of the dimension of actors' involvement issues. This can be understood since they are probably the ones requiring greater adaptation from their work culture. Involvement of subcontractors also depends on their culture and this may comprise additional resistance to change. For example, some of them are more prepared to adopt the new methodology while others are not interested in improving processes.

The training provided at the beginning of the implementation process vary greatly from one company to another. However this is not surprising, since state owned companies

share the mission and responsibility of improving practices at the industry and had more ease to partly finance training to all the personnel involved in the project. Private companies did not have the resources to provide training to all the employees and subcontractors. The highly positive result from experiences where training was provided to a full extent, invite to extend this practice by creating training programs for subcontractors focused on the application of practices. This is aligned with results found by Kim and Park (2006), who suggest to focus on 'how to' implement Lean in practice rather than merely explaining Lean theories.

The practices reported in the interviews consisted in 3 days course using construction with Lego® to show the effectiveness of using Lean. In this way, managers, employees and subcontractors experienced the benefits of Lean in fiction before applying it in the actual project. This resulted in everyone being convinced of the use of Lean practices and aware of how to apply it. Other benefits from the training prior to the project was the team building considerations which also affected in reducing conflicts during the project. Summarizing, training is of course an important investment but it brings important benefits and it can be expected that the need of this training is reduced as the industry adopt Lean practices wider.

Stakeholders' analysis

The stakeholders' analysis is intended to give a broad idea of what is the level of involvement in the implementation of Lean from the different actors, and analyse their needs to improve their involvement.

Top management

Interviewees were asked to give their point of view about the level of involvement of the different stakeholders in the implementation of performance improvement practices. Top management was usually rated with high involvement indicating great support in its implementation. On the other hand, they were also criticized in some cases for having many ideas and supporting initiatives financially, but lacking strategic decisions and follow up of these initiatives.

Aligned with previous statement about the adequacy of implementing Lean in a top-down approach and with almost every author that has study the implementation process of Lean, top management support and leadership is essential for the success of these practices (Bakås et al., 2011; G. Ballard et al., 2007; Cassell, Worley, & Doolen, 2006).

Project Management

At project management level the involvement depends on individual convincement about Lean practices, varying their attitude from reluctant to actively involved. On one hand, actively involved managers are who actually implement the practices. On the other hand, reluctant individuals need to see the results in advance to take part of the change, otherwise they will try to persist on previous practices. Thus, project managers need a deep understanding of the process to have the capacity to lead the Lean implementation. Furthermore, they would benefit from specific goals to adhere to during the project to keep pushing the implementation when the difficulties arrives and to know that they are in the correct path. As mentioned in the interviews, '*if there is no following up of the implementation process, the attempt disappear in the project work'* (Interview 2).

Depending on the culture of the company, sometimes managers are the ones who need to have the personal initiative to get the practices implemented. This is illustrated by one of the interviewees who claimed '*you have to do it yourself and get the other people working with you'* (Interview 2), regarding the involvement of managers in performance improvement practices.

Employees

Very motivated and involved managers does not lead to the implementation of Lean itself. Managers need a group of motivated employees to reach their goals. In this report, employees refer to the group of workers from the main contractor that are under the management level. The level of motivation is similar to the project management group, with some of them decided to implement practices while others are still reluctant towards new methodologies and are only following what is mandated in the project. The ground difference between the two groups is that managers have the ability and often the tools to enforce the use of new practices in their projects.

As mentioned before, workers are often in the origin of the implementation of new methodologies and they show high levels of satisfaction with these practices once they are involved. Even more, when they are asked at the evaluation of the project whether they would like to work under Lean methodologies in future projects they answer positively. Workers who had participated in small demonstration projects reported that they could use these methodologies in larger projects as long as all the personnel involved in the project also do.

All the experiences reported in this study confront one of the biggest critics of Lean. Berggren (1993) strongly criticized Lean for being endogenous to Japanese socio-cultural context with an aggressively achievement-oriented workforce leading to distressing working conditions. The interviews reported that projects with highly critical schedule had workdays of 12 hours in specific points of the project, divided in several workers, and working hours during the weekends. However, this project should be counted as the exception due to the strong needs and requirements from the owner. Effectively, the limits was on the legislation and it was workers choice to commit to the planning. Although this was a short project (13 days), workers mentioned in the evaluation that they would not accept these exceptional situations for a long period of time.

Nevertheless, the cause of these situations is not the implementation of Lean, but the owner's need to have the shortest possible completion time. The freely commitment from workers made possible to achieve both objectives, short completion times and high satisfaction level of workers.

Subcontractors

This group of stakeholders is usually ranked lower than employees, though their involvement for the success implementation of Lean is equally important. The size of the subcontractors, often much smaller than contractors, make that they lack capacity and competence to reach the same level of involvement. Subcontractors at organizational level are often formed for a foreman and a number of workers. This means that they do not have the organizational capacity to think forward about how to improve, and they are mostly focused on the assigned tasks.

Similarly to employees, management in projects can enforce the implementation of certain practices. However, they might find that the enforcement is not straightforward since what they are often facing is the resistance from culture change. In this case is not only organizational culture that needs to be changed, but also the culture of the whole industry, which is a major endeavour.

Those companies with larger practice using Lean have had the chance to look closer at this issue. From their experience with subcontractors, they acknowledge that subcontractors works better using Lean and that is cheaper for them as themselves recognize. However, they still show some resistance to work under this methodology as part of the cultural change. Given the cost advantage for the subcontractors using Lean, owner and contractors mentioned their expectations of subcontractors reducing their prices when bidding for a project under Lean practices, although the time when this actually happens has not yet arrived.

These potential costs reductions would justify the investment in training for this stakeholder, but the question is from whom budget would this training be covered. Training programs should be developed for the effective implementation of Lean practices among subcontractors (Kim & Park, 2006). Particularly in Norway, there is a range of platforms that could serve as the mechanisms for the deployment of these programs. Lean groups, subcontractors associations, research projects and certain sponsorship from the government organizations should collaborate to leverage the full implementation of Lean practices.

Customer or project owner

When it comes to the owner of the project, there is a consensus about their involvement. Interviewees differentiate between public and private stakeholders, giving the highest level of involvement to public owners and the lowest to private ones showing the radically different perspectives.

Public owner perspective is based on the compromise of having a positive impact in the society further than the project itself. First, they can decide to include the use of Lean in the specifications of the project, enforcing its use by contract. Second, they are open to finance the training although it would require also an effort from the contractor. For this

reason is the special relevance that the financial coverage of the training is well specified in the contract. Finally, the training provided should not be oriented towards a specific project, rather intended to provide competence for future works as well. Although this perspective follows the logic of a public company's mission, the decision about the scope of the training, actors involved, etc. holds in the project manager, who may have a narrower perspective in some aspects.

On the private owner side, interviewees agreed on that they were only focused on price. In the best case, they are interested in safety, quality issues or tidiness of construction site. However, it is very common that they want the minimum involvement in the project. From this position, the only way to get private owners involved is to demonstrate that the use of Lean leads to cost savings. This approach would provide them the foundation to ask for the use of these practices in their projects.

Construction Industry in Norway

Considering all the previous stakeholders, interviewees were asked as well about their point of view of the interest of the industry as whole in these new methodologies. Although the interviews were performed to a variety of stakeholders, it cannot serve as a solid foundation for assessing the whole industry. Nevertheless, it can be useful to grasp the general feeling.

On one side, interviewees highlighted the portfolio of research projects in which companies are involved among other initiatives. It is also interesting to mention the relevance of the academia in this process, since often happens that they are closely involved in the beginning of the application of these practices. In contrast, it has been also mentioned that in some cases companies take part of these initiatives more with marketing purposes than with an actual convincement of the implementation of practices.

Summing up, there is a wide variety in the level of involvement when analysing the main actors. It has been seen that the success of the initiatives depends greatly on the motivation of the people involved. Specific needs that should be addressed in order to increase the involvement of the different actors will be further analysed in Chapter 7, where a model is proposed to explain these needs and the interaction among the stakeholders.

Effects of using Lean

In the attempt of implementing Lean, it is important to focus on what can be expected to measure effectively the results of its implementation. Following are the key aspects where companies realized the most significant benefits. This will serve as a base for the development of a measurement system that aims to support the implementation of Lean practices.

The biggest issue raised when asking for the effects of using Lean was the difficulty of measuring whether the improvement came from the implementation of Lean or from other external causes. For this reason, interviewees based the information provided in their personal experience rather than hard data. The purpose of this study is not to demonstrate quantitative improvements achieved by Lean, but serve as a foundation for future measurement. The following statements about the effects of Lean should be reviewed in this context.

Time

If there is any characteristic that deserves a special mention when talking about the effects of implementing Lean is the possibility of achieving a reduction in project's completion time. This is achieved through improved planning and the strong commitment to the plan. The numbers to demonstrate this fact holds first on the reduction of the planned completion time, which was mentioned in all the interviews with practitioners, and secondly on the increased ability to reach project completion according to the planned schedule.

Quality

Effects on quality applying Lean have been reported regarding the number of mistakes and contingencies during the construction, and the list of pending work after completion. This can be seen as a result from improved planning and better cooperation. One example that supports this statement is the pending work list in one of the projects consisted of three bullet points, while in the interviewee experience this usually covered half a page (Interview 3).

Costs

In this aspect there has been very few improvements compared to regular practice. The project manager from the owner company did the simulation of costs for two of the projects using Lean. The findings from this simulation was that both projects would have used almost the same amount of resources independently if they were using Lean or not. There are several reasons for this: it has been noticed that the time spent on planning has been considerably larger when using Lean, requiring more resources. Secondly, all the personnel participating in the project received a three days training on Lean practices, whose expenses were covered by the budget of the project except for the time of the external participants. Third, the use of consultants specialized in Lean was also a significant part of the budget. Under these circumstances, it is reasonable to think that important cost savings can be achieved in the long term when the need for extensive training and consultancy services is reduced. In contrast to what it was reported in the interviews, cost saving is one of the most reported effects in the Lean Construction literature (Andersen, Belay, & Seim, 2012).

Predictability

One of the reasons to start implementing Lean practices for one of the companies was to reduce workers absence rate. The objective was to let workers know what would they do during the week, so they could better assess whether or not they can do that job in case of small injuries. In this sense, the work got very predictable for workers and they got to reduce significantly the absence rate. Moreover, given that the degree of adherence to the plan is higher than when not using Lean, the project became more predictable for the project owner as well.

Defined responsibilities

The use of Lean practices allows all the personnel having a clear idea of who is responsible for each activity and every aspect of the project. As a result, decisions are made without unnecessary delay and in case of defects is easier to find the cause and the solution. It has been reported workers doing their job in a more independent manner, since it is sure that predecessor activities are completed and resulting in less people working at the same time in the area. This has been named '*micro-management*' by one of the

interviewees (Interview 2), and by the description given, it refers to the communication of responsibilities so each person knows precisely to what issues should provide answers. This applies not only to practices at the construction site, but also during the design phase when using concurrent engineering. However, in the design phases happens that micro-management is a success factor rather than an effect. This perspective will be further explained in the next section.

Cooperation

Practices like involving planning provide spaces for communication such as the morning meetings, concurrent meetings, etc. These spaces facilitate effective communication among actors in a structured fashion. Workers learn to adapt to each other and the bad feelings when it comes to changes are reduced. This adaptation is probably the clearest picture of what it was expressed on the Lean Construction model (Figure 8 in page 88). At the same time, the team building effect increases the proudness of the workers when achieving their own objectives. In this way, the traditional individualistic perspective from workers acknowledged during the interviews is transformed towards a project team perspective.

Happier people at work

This effect can be seen as highly subjective, however it is one of the effects that has been actually measured in a number of projects through worker satisfaction indicators and reported as of great importance. This was made by monthly surveys in which workers could evaluate safety conditions, tidiness, collaboration or their perception on predictability among others aspects in the project. This practice was being developed in the company with wider experience using Lean, and workers' satisfaction reached a score of 6.1 over 7. The target for every aspect measured was set above 6 in a rank from 1 to 7. Once the manager obtained the results, the project would focus the improvement in the indicator with less score.

Another effect is that there are fewer conflicts as a result of improved planning and the team spirit created before the planning. Having a positive team spirit could enable the alignment of interests towards the project objectives. In this regard, Tabish and Jha (2012, p. 1137) found that '*human factors play a decisive role in making a project successful'*.

More specifically, absence of conflicts and satisfaction are mentioned by Elattar (2009) as success factors in construction projects, and teamwork is one of the factors included in his framework. Li, Lu, and Peng (2011) place 'keeping and promoting good relationships' in the first level of their success factors framework in construction organizations. Other authors rely on managers' competence and experience to provide coordination and conflict resolution (Gudiene et al., 2013). On the contrary, Lean methodologies give the opportunity to workers to add value to the project and these coordination and conflict resolution abilities are transferred to the project team.

Learning

The last effect that has been mentioned is learning. It is obvious that nobody can expect to implement Lean with any difficulty and obtaining the best possible results from the very first project. The implementation process is at the same a learning process. Some companies decided to try out some practices without any particular training program or consultants support. Even those projects that had the training still realized some key learnings during the first projects. Organizational learning tools should be used to obtain greater benefits from these experiences and facilitate the implementation of practices in future projects based on the lessons learned.

Lean practices have provided also tools to enhance learning during the project. In some of the projects, there was a list with mistakes made along the project in the room where they had the morning meetings. In this way, they could avoid repeating the same mistake during the project and make effective the learning process.

Some of the effects presented are part of the initial goals of implementing Lean while others are spontaneous benefits of using these methodologies. Although they cannot be quantified at this point, it can be expected that this is done in the future to provide more solid fundamentals. Despite of this, the observed benefits using Lean justify further use of these practices.

Barriers and Success Factors implementing Lean

In the previous section, the benefits obtained from using Lean were explained. However, it should be recognized that during the implementation process companies had to

overcome a number of difficulties. These barriers are presented together with those factors that had the ability to leverage the implementation process. The factors presented should be considered as well in the measurement system to obtain the desired results.

Motivated people

The first experiences with Lean may have a huge impact in its implementation, since they will serve as examples for what can be achieved. If the results from the first experiences are positive, will be much easier to convince other teams. While if the results are worse than using prior methodologies, it will be difficult to support further these initiatives. For these reason, motivated people towards new methodologies and positive to change should be involved in the first projects to make them success. Top management knows who these people are within their companies, and one important way to support new practices is prioritizing motivated personnel to these projects. Training to provide basic knowledge and following up their progress is the fundamental support needed from the top management.

The right people are those ones that are convinced that the new practices will work. Implementing new practices is a challenge itself, so culture change barriers should be avoided to the possible extent. If part of team, workers or management is not convinced, it will hardly be implemented successfully due to the internal resistance. For this reason, finding the right people is the first barrier to be considered.

Involve all the actors

And when it is said all, it is meant all. During the interviews was mentioned in several occasions the common fact in Norway that a good part of the work force are foreigners that in some cases do not even know the language. Furthermore, they often have a quite different culture and for example, they would not speak up if there were something wrong, they would not speak towards the leaders and they would not say if they do not understand something. The solution to overcome this situation is not more isolation, but teaching them the Norwegian culture. Sometimes they do not have more motivation for their job than getting the work done. The results obtained in projects where really everyone was involved, both in training and in practices, indicate that it worth to involve them all as early as possible to get into the mind-set of the project.

One of the effects mentioned in the previous section was micro-management of responsibilities and tasks, making that workers know what they have to do and when exactly. At decision-making level, and especially during the design phase using concurrent engineering, it is important that decisions are made to keep the work on. Experiences with concurrent facilities from the airspace industry shows the importance the decision-making process. Bandecchi et al. (1999) highlight that team members participating should be ready to provide answers in real-time so the work does not stop, putting more pressure on engineers. For this reason and because of the need of being motivated who participate in these initiatives, Smith (1998) recommended that taking part of these meetings remains voluntary.

Plan, plan, plan

It has been necessary in the projects to use more resources on planning. This seems logical since there is more people spending more time doing the planning. The result is more accurate project plan, with greater commitment to that plan from the workers. Moreover, the project plan, procurement plan and production plan should depend on each other and fit together. The idea of Lean as a continuous flow is well represented in this success factor as well as the 'train model' of Lean (Figure 8). The smooth operation is not achieved naturally or by chance, rather is the outcome of precise planning of all the processes involved in the construction.

Competence

Recent studies has shown that Norwegian companies rate very high the work experience when performing planning activities (Hoseini, 2015). This can be understood when considering traditional methodologies. However, in the implementation of new practices just experience may not suffice and the development of appropriate competence is required. If managers with extensive experience in planning would need training, it is obvious that workers who will become involved in the planning would need also the training.

Furthermore, the training could serve as a tool to overcome the culture change resistance. It would be very difficult to force employees at any level to use a certain method when doing their job, but you can force them to apply these methods during the training with

no resistance. The training from one of the companies consisted in a practical course where all the people involved in the project could test the methodologies to be used during the actual construction work and compare the results with the traditional methods. Once they could see the results in practice, it was no longer necessary to convince them about the benefits of the new methodology while building team spirit at the same time.

Another aspect related, is that the previous stakeholders' analysis performed showed that subcontractors lack the competence to apply Lean practices. It can be assumed that the involvement of actors is only effective when they have the necessary competence. In conclusion, the benefits of providing extensive training are too significant to dismiss this practice without thorough consideration.

Top-management support

From the manufacturing experience in implementing Lean, Cassell et al. (2006) concluded management support plays a strong role in this process and pointed as one of the reasons for failure not providing a consistent education effort accessible to all employees in the organization. G. Ballard et al. (2007) described the Lean preparation process prior to its full implementation. This process included the need to have strong commitment from top-management, which could be gained after two successful pilot projects. Other elements were a Lean task force team, external consultants, training to the managers and engineers involved in the pilot projects.

Interviewees mentioned explicitly that Lean should be introduced in a top-down manner, making employees understand the importance of adopting the new system, and from project owner to subcontractors. The ability to influence the practices from the owner and the hierarchy in policies between the organizations participating in the project can support this argument. During the interview held with the engineer responsible for new methodologies in design, it was mentioned the importance of top-management providing direction though strategic decisions and the need of following up the initiatives, which also suggest a top-down approach.

On the contrary, Arayici et al. (2011) found that technology adoption for Lean architectural practice should be done in bottom-up approach in order to engage the people in the adoption and reduce resistance to change. It is unreasonable to think that an easy

answer can be found regarding organizational change, but what it might be a compromise solution is to take the top-down approach while keeping voluntary the participation in these projects. However, the data collected does not allow reaching a solid conclusion on the ideal approach and further research is advised.

Inaccuracy of drawings

Another issue that is often linked to Lean practices as it has been observed in the literature review is quality in the production process. Lack of quality in the process may have a potential impact not only in the product, but also in the planning or costs. Inaccuracy of drawings has been reported as one important barrier during the implementation of Lean. The reason is that these issues lead to 'ad hoc' work, meaning improvised solutions, possible rework and interruption of the planned tasks, which can be identified as waste in the context of Lean. The use of a technical office to solve these problems may help to solve the problems at the construction but does not avoid that the mistakes are repeated.

Detailed investigation on the causes for the inaccuracy of drawings is out of the scope of this study. However, this subject can be object of further study. It worth to insist at this point that Lean is not a set of practices and tools, rather a new paradigm or mind-set for the continuous improvement of processes (Koskela, 1992). There are specific methodologies linked to Lean that could be used for the improvement of processes, such as the House of Quality (J. R. Hauser & Clausing, 1988). The objective should be to improve the process so the failures are not repeated instead of looking for patches to solve the issues every time they happen, emphasizing the holistic approach of Lean practices.

Measure improvement

Every barrier, success factor and effect described before have a common obstacle to be applied in process' improvement: currently is not possible to measure where the improvement come from or to what extent new practices improve performance. This fact has been mentioned during the interviews as a main barrier for Lean implementation as some previous examples have already indicated. Looking at the situation in Norway, Langlo et al. (2015, p. 4, own translation) claim that '*the fact is that we do not know how productivity is developed in the construction industry as a whole'* as a result of lacking

tools for its measurement. This shows the need for prioritizing the establishment of performance indicators and measuring results.

Performance Measurement in Projects

The first point to highlight regarding the measurement of performance in projects is the perception of employees on these measures. A common answer during the interviews and even during previous phases of this study when asking for the interviews is that they do not measure in projects. Even without further questions, it is not difficult to think that the answer is not completely true. In every construction project, there will always be some costs that are measured and a schedule to be followed. Not to mention HSE issues enforced by law. Consequently, there is always some measures in projects. What makes the difference is whether or not they are used to generate improvements.

Further inquiries with the interviewees showed that they actually brag about having excellent HSE systems to measure and ensure adequate performance. Interviewees also commented that they measure based on the plan and using man-hours as basic metric. At this point, they also realized the difference in measuring between Lean projects and others. While the measure of the advance of the planning was traditionally done in a meeting with managers and personnel responsible of the different areas every two weeks with common inaccuracies on the status of the tasks, Lean projects kept continuous measurement of works being the workers who pointed when the tasks were finished. One of the benefits realized is improved information transfer towards decision makers, which is a key factor in the effective use of early warnings in projects (Haji-kazemi & Norges teknisk-naturvitenskapelige universitet Institutt for produksjons- og, 2015).

Another aspect of measuring performance in projects is how projects are evaluated within the organization. In fact, this measurement may have a great impact in employees behaviour since shows how the organization measure success. In some of the companies, interviewees admitted that the evaluation of projects was based exclusively on costs, having the schedule as second metric with much less importance. This is aligned with the findings from Andersen et al. (2011, p. 321), who claimed that '*projects are measured by whether they complete on time and on budget'*. As detailed previously, other companies

with higher degree of Lean implementation used workers' satisfaction as part of the project's evaluation.

Characteristics of the Performance Measurement System

Finally, interviewees were inquired about the characteristics of a hypothetical measurement system in their organizations. Based on performance measurement frameworks studied and the insights from the report '*Prestasjonsmåling i norsk BAE-næring'* [Performance measurement in the Norwegian construction industry] (Langlo et al., 2015), interviewees were asked to rank the characteristics of this system resulting in the following attributes.

There is a number of articles in the literature comparing the generic frameworks discussed in Chapter 3, and one basic differentiation among them is their ability to implement the corporate strategy against the ability of benchmarking projects (Vukomanovic & Radujkovic, 2013). Interviewees showed a clear position in favour of benchmarking projects. This can be understood given the need of finding out whether the improvement comes from the implementation of new methodologies or other circumstances. On the contrary, the performance measurement system could benefit from having the ability to implement strategy as part of the guiding managers' decisions and following up implementation of new methodologies. This aspect appeared in the second characteristic, where interviewees' opinions were divided between measuring specific initiatives or general project's performance. Even those inclined towards general performance mentioned that specific initiatives would have effect on the global project performance.

All of the interviewees also expressed the importance of having the focus on the value chain performance, from subcontractors to society, rather than being limited to internal organization's performance. However, it was also acknowledged the magnitude of this endeavour and they showed appreciation for internal measurement in an effort of being realistic at first.

They judged the measurement system to be centred on decision makings, meaning that it should serve managers to make decisions to run the project smoothly and be able to adapt.

Other opinion in this regard was being centred at operational level, given that is at this level where the improvement is obtained. Regarding at what level should be measured, interviewees agreed on not measuring personal performance but keeping the feedback at project's team level. This is reasonable in order to avoid personal judgement on weak team performance. From these couple of questions, can be concluded that is important to provide feedback at team level on how to improve performance, but the system should be centred at project management level to give the possibility to drive the project to success.

When asking for the possibility of providing information during the project or just at the closure, they were inclined towards the first option. For the same reason as the previous conclusion, is important to have the ability to take action during the development of the project. At the same time, this option covers the possibility of providing information at the end of the project by aggregating the data collected.

Finally, although all the companies have in place an information system, they were unsure that the new measurement system could fit into their current system. It is important to use as much as possible the current systems to avoid adaptation to new technology being a barrier for the system users. On the other hand, new features within the same system or possibly a new system able to meet the expectations may be required. In any case, this particular aspect will be decision of each company depending on their current systems and its ability to support new features.

Summary of the chapter

The basic constraint of the data collection is related to the lack of measurement culture in the industry although it could be reached a variety of stakeholders resulting in fruitful data collection. From the interviews, four practices were found as the most used in the Norwegian construction industry: Last Planner, Pull Scheduling, Concurrent Engineering and Virtual Design Construction (VDC). The fundamental concept of Lean from practitioners' perspective is revealed in Figure 8: The Lean Construction Model, represented as a 'construction train' in which all the activities should be coordinated and stakeholders involved over the project lifecycle for the success of the project.

Next, the most relevant aspects in the implementation of Lean practices were highlighted including a stakeholders' analysis. Top management is usually supporting the implementation of practices, although strategic guidelines and following up of initiatives are often insufficient. This is required by project managers to drive the project under the new methodologies. In addition, project participants both internal and from subcontractors require the competence for applying the new methods and the convincement that they work better than previous practices. Project owners should be key actors of the implementation process as they can ask contractually for using these practices, although costs reductions need to be proved for its implementation out of the public and bigger owners.

The primary effects in the use of Lean are described as well as the most significant barriers. The effects found refer to completion time, quality issues, costs, predictability of project activities for workers and project owner, better defined responsibilities, increased cooperation, more satisfied workers and facilitated learning. Motivation, involvement of actors, top-management support and measuring improvement are among the success factors found in the implementation.

The current use of project metrics is mostly limited to cost and schedule especially at the evaluation, though companies have declared expertise in HSE issues. Finally, aspects related to the desired characteristics of a measurement system are described, emphasizing the need to provide feedback at team level while providing direction at decision-making level, and to compare projects through benchmarking tools.

Chapter 7:

A Performance Measurement Model for Lean Construction

This chapter presents the models that I have developed based on the data analysis previously presented. First, a model on stakeholders' needs will be discussed based on the prior stakeholders' analysis. This model aims to make explicit what the requirements are for the different stakeholders in order to achieve a successful implementation of Lean practices.

Second, I will present the Performance Measurement model for the implementation of Lean Construction together with some tools for its successful implementation. This model responds to the main research question about how the effects of Lean can be measured. In the first place, the performance measurement model shows the basic elements required to implement Lean according to the success factors described in the previous chapter and the effects that could be found during the implementation process. In the second part of the model I linked the possible effects with specific Lean practices to guide the creation of indicators and support the decision making process on what practices the organization should implement. These connections are made based on the effects exposed by the interviewees according to the practices implemented in their projects, and other relations found in Lean theory.

In the last part of the chapter, I will purpose some guidelines for the actual measurement of the expected effects. Although the model does not comprise a specific set of indicators to be included, I will explain the characteristics that indicators should fulfil to be sound measures. Then, I suggest a project evaluation framework according to the desired characteristics expressed by interviewees and gathered in the previous chapter.

Finally, I expose the logic of the whole system through a step-by-step roadmap for the implementation of the model within the boundaries of the thesis' limitations.

Stakeholders' needs model

In the previous chapter I have explained the details about the current status of Lean practices within construction companies, their understanding of the topic and the analysis of the stakeholders' involvement during the implementation of Lean. This analysis can be summed up into the stakeholders model that I have created reflecting the requirements from each group for the successful implementation of Lean practices.

The first step for creating a model supporting the implementation of practices requires looking closely at the situation of every stakeholder involved in the process. If organizations are currently facing some difficulties when implementing Lean can be assumed that is because there are certain uncovered needs. It is the vital importance for the future success to reveal the needs of the stakeholders, so the model could provide solutions about how to address those needs.

Figure 9 shows the different stakeholders divided into external or internal based on a main contractor perspective. Three specific needs are identified from the stakeholder analysis in the discussion and the model use coloured arrows to indicate whether the stakeholders have each need (arrows from needs to stakeholders and coloured differentiating between orange for internal and blue for external stakeholders) or they have the ability to cover those needs (green arrows, from stakeholders to needs).

The first need identified is to have strategic decisions that guide the decision making process and have a follow up from the management. Project managers are the main actors claiming for this as mentioned in the stakeholders' analysis. Whereas top-management at

organizational level and project owner, both private and public, can provide these strategic decision at project level.

The second need identified is the ability to measure results, and this seems a greater challenges since are many actors requiring this need but few able to provide it. This challenge is also identified in the literature (Andersen et al., 2012). It has been often mentioned during the interviews the difficulty on measuring the effects of using Lean being sure that is not circumstantial improvements. Contractor's top-management and public owners have some initiatives for implementing Lean and they need to prove that the results delivered come from Lean implementation to extend further these practices. On the private owner side, they would need proof that using Lean methods lead to cheaper project in order to enforce their use by contract and provide the previously mentioned strategic decisions.

The improvement can only be measured at project level, and therefore is the project manager who could deliver those measures. However, the project manager would need to make use of some tools for measurement and improve the practices in their practices. Therefore is indicated a dual relationship between project manager and the need of measuring results. This need suggests at the same time that a performance measurement system attending the effects of Lean could be a very relevant tool in the Lean implementation process. As seen in the implementation process literature, this statement is aligned with findings from other authors which mention the establishment of a performance evaluation system as a critical success factor (Bakås et al., 2011).

The third need identified is training, which aims to cover two underlying needs: motivation and competence. Stakeholders requiring this need are project managers, contractor employees, subcontractors and in general, everyone involved in the use of Lean practices. This has been mentioned in the interviews and reflected in the previous chapter as the need of everyone been convinced about this practices to make it work and increase competence at subcontractor level to increase their involvement. This would produce alignment of personnel behaviour with project practices. For this reason, these will be presented as well as enablers in the performance measurement model, and making use of Senge (2014) mental models to explain how to drive the change in the construction culture.

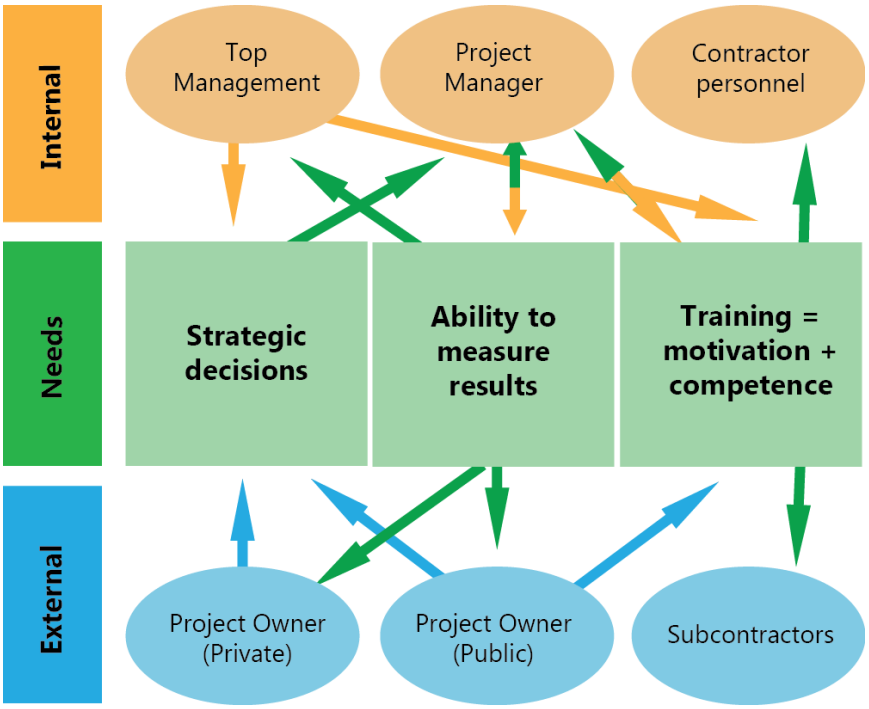

Figure 9: Stakeholders' needs model in the Lean implementation process

These needs are basic foundations for the performance measurement model and they are clear candidates to take part of the enablers in the implementation process. Although these needs have been reflected before in the literature, their relation to the project's stakeholder can provide an additional insight on how to satisfy those needs.

Performance Measurement Model

The stakeholders' needs model presented give some first clues about important aspects in the implementation of Lean that should be addressed. Along Chapter 6 other relevant aspects as the enablers or most of the effects of the model have been also mentioned. Furthermore, it is important to notice the interrelation of the different effects, barriers and success factors as often discussed during the analysis of the data. However, the correlation among the different elements of the model is not possible to be evaluated with the data collected and it represents a limitation of the model.

In order to enhance the effectivity of the model, several of the most successful performance measurement frameworks have been reviewed in the literature. The references that have been used to explain the models do not only focus on the model itself, but mainly in their implementation in organizations. The purpose of the model presented

is not only to serve as a theoretical reference, but intends to facilitate the implementation of Lean in practice.

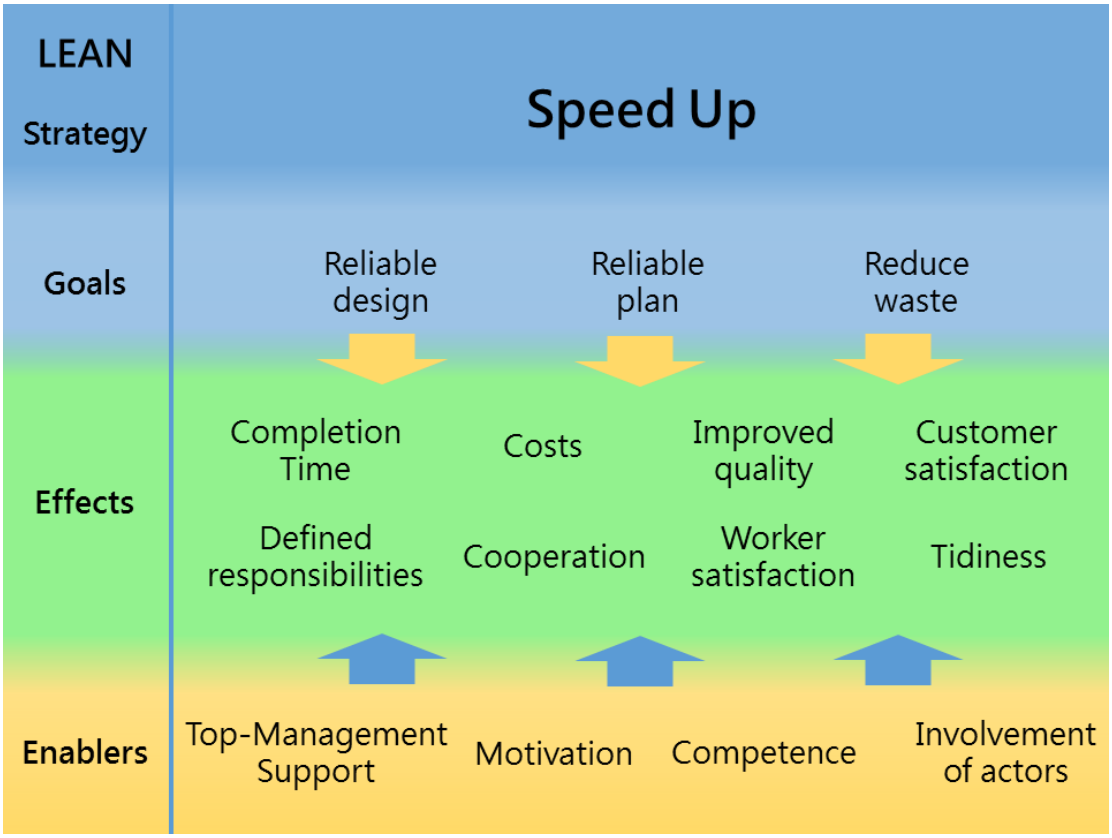

Figure 10: Performance Measurement Model for implementing Lean Construction

Some of the characteristics that have been pursued when designing the model are connected with the virtues of the generic performance measurement frameworks, the expressed desires of the practitioners and simplicity for ease understanding and application. The result is revealed in Figure 10 and explained in detail next according to the different levels of the model: strategy, goals, enablers and effects.

Lean strategy

The first look at the model suggests a strong relation with the Balanced Scorecard (presented in page 29) given the importance of the strategy as a first step of the model. Effectively, the implementation have been seen more effective when the management was directly involved in the initiative, and several interviewees have mentioned the need of a top-down approach.

Since the model is particularly focused on the implementation of Lean, it is important to include in the strategy some elements that lead to implementing Lean. The implementation of Lean should not be the goal, but just the mean to achieve greater performance. At this point was very helpful the insight from the Lean Six-Sigma model. In the aim of assembling together Lean and Six-Sigma practices, the literature revealed the key contributions from each model. As defined by M. L. George et al. (2006, p. 39), '*Lean means speed'.* For this reason, the model indicates that part of organization's strategy should contain a reference to speed up processes, which in the construction context could be translated in the ability of completing projects in less time.

Goals

The Balance Scorecard model defines the strategy map as '*What must we do well in each of the perspectives in order to execute the strategy?'* (Niven, 2002, p. 98). In this case, the model does not consider the perspectives proposed on the Balanced Scorecard model, but this step should include the necessary goals to achieve the strategy. Given the narrower perspective of this model compared with BSC, is possible to define those goals to achieve the speed up of projects.

Three goals have been found necessary to reach the upper strategy. First, having a reliable design that is able to produce drawings describing the reality and anticipating problems on site. This should not be incompatible with flexibility, and practices from other industries using concurrent engineering have shown the possibility of achieving both purposes, reliability and flexibility (Limon, 2014). Second, having a reliable plan is crucial as a basic measurement of schedule in projects. It is not possible to reach shorter completion times if the project is not able to meet the plan. The ability to produce a plan shortening the schedule needs to be supported by practices able to follow the plan or even contributing to the objective.

Finally, it is necessary to reduce waste as indicated by Lean principles. In this regard, the analytical focus of Lean Six-Sigma is also useful specifying the type of waste and making more explicit the basics of Lean. M. O. George (2010) provide a detailed explanation of the seven common faces of waste summarized in the acronym TIMWOOD. According to this, waste can be reduced first from transportation, which can be the result of inappropriate layout on site or lack of flow between process steps. Waste can also come

from inventory, which can be recognize as Work in Progress in manufacturing terminology, and in construction can be translated as mismatches between supply and demand throughout the supply chain or current work being performed as seen in Andersen et al. (2012). Motion can be also a waste when is not necessary, and this situation can be as simple as workers forgetting their tools. Next waste is waiting, and the best tool for this can be a well-communicated plan in combination with pull scheduling as experienced in some of the projects related during the interviews. Overproduction, most typical in manufacturing but often experienced in construction through overpurchasing, for example when ordering more materials than necessary because of unit-price based decisions (Vrijhoef & Koskela, 2000). The second O stands for overprocessing and it is produced when delivering more value than needed from the customer. Finally, and probably the most obvious waste are defects. Rework, repair and customer escapes are part of this category. Focusing on reducing defects in high cost areas could have a great impact saving costs, but probably also timesaving.

Three main goals have been explained as explicitly as possible to understand the link between the strategy and effects. The goals described might be quite generic and the intention is not that a company is focusing in each of the elements of these goals. The broad description of these goals can actually give room to companies to focus on certain areas while keeping the validity of the model. Optionally, each company can narrow the exact meaning of the goals by giving a more explicit definition, which would help to understand the logic of the system and produce more accurate indicators in the following steps.

Enablers

It might be surprising for the reader to find at this point the enablers before the effects. Well, this is completely intentional and it is indicated by the blue and yellow arrows in the model. The inclusion of enablers is a clear influence from the EFQM Excellence Model (presented earlier in page 46) and an attempt to explain the need of a bottom-up approach. However, this approach should be facilitated by certain elements mostly addressed in the stakeholders' needs model.

The first enabler is top-management support, and as described before, this must consist not only in a defined budget but also through establishing a clear strategy (as pointed in

the top-down approach of this model) and following up the implementation process. These two aspects go hand by hand, since it is much easier that top-management follow up the implementation when is part of organization's strategy.

The second enabler is motivation. As explained in the discussion, the construction industry has a very strong culture that represents significant resistance to change. Some of the interviewees claimed that many of the workers are not interested in new methodologies and they just want to get the job done. This attitude is mainly found in subcontractors. Within the contractor, arguments against new methodologies are more focused on bringing more problems than benefits and some workers at all levels prefer to do the work as usual. In order to address this challenge is useful to mention the mental models described in Chapter 4 from Senge (2014).

The Ladder of Inference (Senge, 2014) shows how people take actions based their beliefs after a process stating in observable data and experiences. For this reason, the stakeholders' needs model presented previously links motivation with competence, the third enabler. Motivation and competence are tight together in this mental model and it can be facilitated by providing training at all levels of the project organization.

As it was mentioned during the interviews, it is difficult to force workers to adopt specific practices while they are doing their job, but it is possible to force them during the training. In this way, 'observable data and experiences' are provided to the employees by participating in practice-focused training. They will select the data from what they observe and add meaning. It is expected that after seeing how Lean works with some practical examples, for example using Lego® constructions, employees will make assumptions based on the meaning added to the data observed, so they are able to draw their own conclusions. From these conclusions, they adopt beliefs that will allow them to take actions accordingly. When walking the same path regarding their actual work, the reflexive loop make that current beliefs affect what data is selected next time, helping to have a positive attitude towards Lean practices in the real job.

This explanation also provides foundation for the last enabler, involvement of actors. It may happen that only part of the project's crew have walked the Ladder of Inference of Lean. These employees will have very positive attitude and good energy towards the

change. However, people who is still not convinced can easily bring much greater resistance and threaten the successful implementation of Lean practices. For this reason is important that all the people participating in the project get involved as well in the training.

Now that the enablers have been described and both approaches, top-down and bottom-up, have been initiated is possible to go through the resulting effects that should have the attention according to the performance measurement model.

Effects

The effects enounced in the model may remind the section of results from the EFQM Excellence Model. Again, in this case the effects are intended to be more explicit given the precise focus of the model. The objective of these effects is to provide guidance when developing the final KPIs to be used in practice. Effects are not indicators, but they express a range of attributes where indicators could measure performance. It is neither the intention that one KPI should be developed for each effect. As will be explained later, the organization should develop a set of indicators according to some specific effects that they have identified as key for the strategy of the organization.

Most of the effects collected in the model have been extracted from direct experience of Lean Construction pioneers in Norway. Two of them, although not being explicitly mentioned during the interviews as primary effects of implementing Lean, their importance is enough foundation for being included in the model. These effects are costs and customer satisfaction.

Although the costs are not the first parameter to improve, it is certainly a very important part of every project evaluation if not the only one. Some of the companies participating in the interviews have performed a simulation of costs, showing approximately the same budget needs independently of using Lean or not. However, a significant part of the budget in Lean projects cover training of all participants and the use of Lean consultants. It can be expected a positive evolution of costs after certain experience with Lean projects reduce the need of consultants and all the participants have received adequate training. The cost savings have been also found as outcomes of Lean implementation in the literature (Andersen et al., 2012).

Customer satisfaction is, or should be a necessary condition for accomplishing the mission of the organization. Furthermore, Lean should bring specific benefits for them such a better understanding of the final product, shorter delivery, building with less mistakes or minimized pending work after delivery. The tool that can help to a bigger extent to achieve this effect is Virtual Design Construction (VDC) as a mean to provide precise visual information about the product using 3D models. When the model was reviewed with practitioners for testing its validity, they agree that *'no one could discard customer satisfaction as a relevant issue'* (author's translation from the interview in Norwegian, Interview 8).

From the effects that have been reported as direct benefits, the most relevant is the ability to reduce completion time in projects. Furthermore is directly linked with the strategy as well, so there should always be some indicators quantifying this effect. Lean practices such as Pull Scheduling, Concurrent Engineering and Last Planner (involving planning) contribute directly to reduce completion time.

During the interviews was also reported a better definition of responsibilities, which may lead to improved flow of work and less disagreements during the development of the project. Last Planner and Concurrent Engineering are the practices that could better increase this effect as a result of involving actors in the decision making process for the planning and design.

Tidiness is also one of the most common effects that are realized when using Lean. This effect can be translated in a more structured building process, less disturb between workers working in the same area and reduced risk of accidents for workers. Last Planner, Pull Scheduling and Concurrent Engineering are the practices that could found direct benefit in this effect and further development of indicators could be considered.

Practices enabling involvement of actors are connected also with allowing further cooperation. This would increase the ability of solving problems raised during the construction, finding an optimized design among the areas involved and the ability to meet the plan. This effect can be directly linked to the use of VDC, Concurrent Engineering and Last Planner.

Another important area of improvement realized by using Lean according to the findings from the interviews is worker satisfaction. In many industries, worker satisfaction has been used as an indicator anticipating customer satisfaction (Parmenter, 2010). In construction, worker satisfaction could be linked with safety and a positive attitude towards change, which can be crucial in the implementation process. Given the higher degree of involvement of workers, Last Planner is the Lean practice that could have direct effect on worker satisfaction. Although it could be reasonable to question how worker satisfaction can contribute to reduce completion time in projects, practitioners emphasized its importance in the Lean implementation when presenting the resulting model, which could be influenced by strong correlation to other elements of the model though this could not be tested in the present study.

The last effect to be mentioned is improved quality, which in practice is translated in less mistakes during construction and fewer elements in the list of pending work after accepted delivery. Furthermore, cooperation and actor's involvement could serve as foundation for increasing quality when using Concurrent Engineering, VDC or Last Planner. The interview with practitioners presenting the model also revealed the inclusion in this aspect of what it is called 'better building'. This concept, often use in the construction language, includes aspects like '*less warranty claims as a result of defects in the construction, and the higher level of energetic efficiency'* (author's translation from the interview in Norwegian, Interview 8).

Associating Lean Practices with Performance Effects

The effects described should serve as a guidance for developing further indicators. As has being mentioned through their description, there are certain Lean practices that have direct impact on some of the effects. Figure 11 shows visually these relations and may serve as a guide for associating specific Lean practices to their most direct effects.

The relation between the effects and the specific practices has been found through the comparison of tools used in each company and the most prominent effects reflected, together with the insight from the literature on benefits encountered in the use of practices. Furthermore, a deeper study of the functioning of each practice in other contexts than

construction industry can provide useful links with the possible expected effects (Limon, 2014).

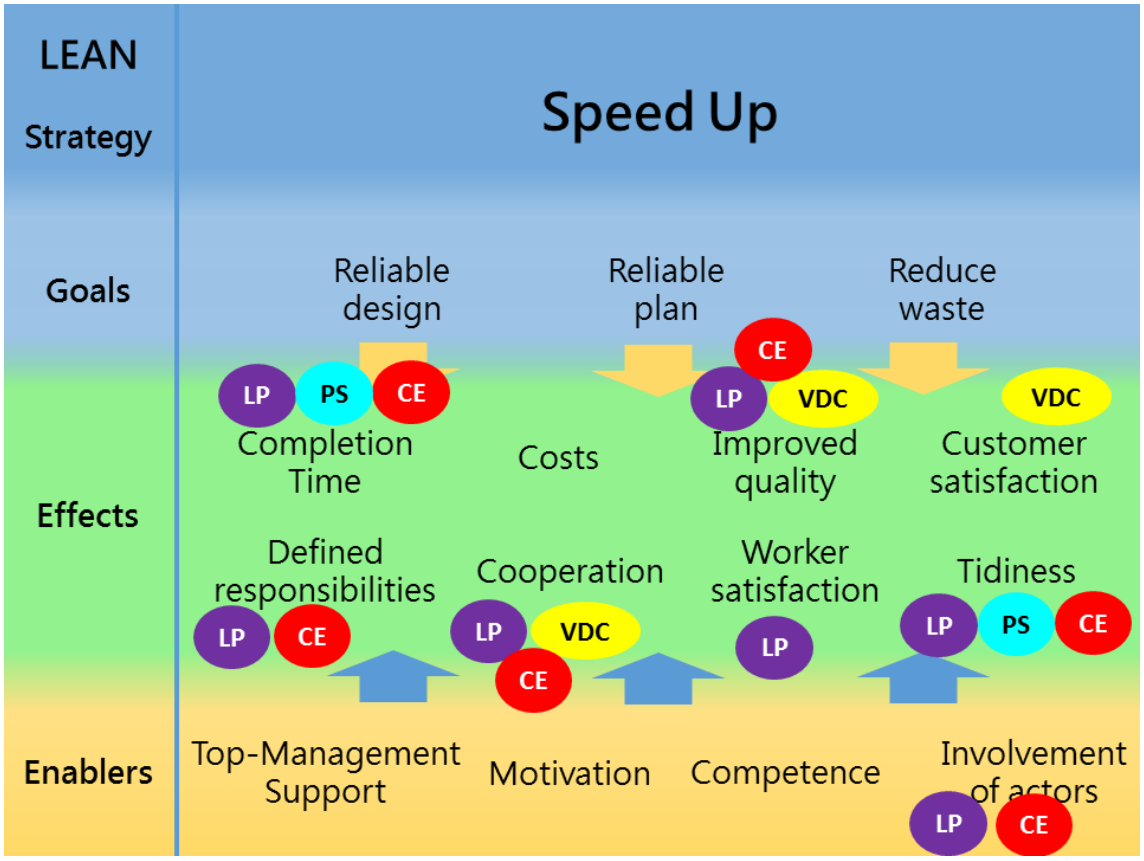

Figure 11: Practices Associated to Effects in the Performance Measurement Model

Legend to Figure 11:

LP Last Planner
CE Concurrent Engineering
VDC Virtual Design Construction
PS Pull Scheduling

Figure 11 could be read in two directions. First, considering that the organization has already started the implementation of Lean practices and it could require the measurement of its effects in order to sustain the implementation process. In this case, the organization could make use of this model to know which effects are preferable to look at. On the contrary, organizations contemplating the possibility of implementing Lean practices to achieve their strategic goals, could use the model to assess which practices could better support their strategy. Some authors mentioned the importance of focusing in the

implementation of few practices at a time to allow the organization acquiring fluency in their use instead of implementing all practices at a time (G. Ballard et al., 2007). Thus, the value of this model is to provide information about in what practices the organization should be focused.

Summing up the Performance Measurement Model for the Implementation of Lean practices, it starts by establishing a strategy aligned with Lean as it can be speeding up project completion. The way to accomplish this strategy is through a feasible, accurate design, reliable planning and waste reduction in processes in any of the TIMWOOD faces of waste. The bottom-up approach should consider four enablers: top-management providing guideline and following up through strategy, motivation, competence and involvement of actors. Training can play an important role in the development of these enablers. Finally, depending on what practices the company is focusing on the search of indicators could be directed to the associated effects. And the other way around, in case the company has not already a strong dedication in specific practices, the organization could choose certain practices according to the effects more closely linked to their strategy. Independently of the case, the model could guide the development of KPIs using the effects provided and associated practices.

Following will be presented a set of indicators that could be used as an example, and most important how to analyse those indicators to find out if they are the most appropriate for supporting the implementation of Lean practices.

Considerations for Developing Sound Indicators

The eight primary effects formulated in the model are not defined indicators, but are essential areas from where indicators can be developed depending on what the organization is focusing on and what Lean tools is adopting. As described in the theory of KPI, most of the authors agree on having less than 10 or 20 indicators (R. S. Kaplan & Norton, 1992; Parmenter, 2010). However, these models refer to a measurement system for the whole company. On the other side, Andersen and Fagerhaug (2002) claimed that the maximum amount of elements that the human brain can digest visually at the same time is seven. In general, it is a wise advice to try to reduce the number of KPI to a

minimum because this will allow the organization concentrate better on their main objectives.

The basic idea when defining the number of indicators could be 'do not bite off more than you can chew'. By focusing on few specific indicators, the organization will be able to achieve greater results on those measures. On the contrary, having too many indicators can difficult the realization of results in all of them. According to Parmenter (2010), it is recommended to choose one or two indicators to monitor daily with the aim to have a closer follow up from the top management. As will be seen next, the process for defining the final set of indicators should be iterative in order to attain a balanced set of indicators.

More than just PPC

The indicators should be chosen accordingly to organization's strategy focus, practices implemented and measurement internal culture. One of the easiest indicators to come up when implementing Lean, and specifically Last Planner is the Percentage Plan Completed (PPC) defined by H. G. Ballard (2000). However, it has been found during the interviews that some companies did not find this indicator as helpful as expected, and their argument was that there could be many factors affecting this number. Conversely, this argument is exactly the problem and the solution. If PPC is only measured as a value is true that it does not provide much information for improving. The important part of measuring PPC is to analyse the root causes for that value. For this reason, it is proposed that PPC is used together with the 5-WHYs tool.

The five why's tool is a common method for finding root causes consisting in asking up to five times the reason for the event happening in order to find the origin reason causing the problem. There could be a set of causes that are often mentioned and could help to indicate where to improve. Some ideas for the root causes could be non-well defined allocation of responsibilities, lack of actors' involvement or any other of the TIMWOOD faces of wasted mentioned in the theory. Furthermore, it could be interesting to apply the Pareto principle, which claims that the 80% of the reasons for deviation would come from a 20% of the causes allowing great improvement by focusing on few factors. This tools and some are described in Andersen and Fagerhaug (2002).

Balanced KPIs

During the challenging process of finding the KPIs, the most important aspect about the indicators is that they need to be balanced to correctly evaluate the current performance and at the same time provide information to drive the change when having poor performance. The analysis and characterization of indicators has been extensively covered in Chapter 3 and Chapter 4, and therefore will not be a central area of the results. However, it is relevant to sum up a number of aspects to look at when analysing indicators.

First, whether they are past-, present-, or future-focused depending on when the action measured take place as described in Figure 5: Focus and validity horizon of measures (adapted from Andersen & Fagerhaug, 2002). Future-focused measures allow taking action to correct deviations from the outcomes, however they are usually not as precise as past-focused measures. On the contrary, past-focused measures have the ability to evaluate whether the desired results were obtained, although they do not allow anticipating action to correct deviations. Present-focused measures provide information about the current performance, although actions taken based on this data can usually impact the short-term results. As a consequence, a good set of indicators would combine past-, present-, and future-focused measures to assess the performance while guiding actions to achieve improved results. As described in the literature, this characterization could also be done as leading or lagging indicators, although this manner could be more confusing to assess.

Second, the timeframe when the indicators are reviewed should also be consistent with their ability of driving future change. For example, if a certain measure is present-focused but reviewed monthly, it completely missed its purpose. Therefore, when creating the set of indicators it should be defined together the frequency of the data collection and the period when they are reviewed to allow taking action effectively and serve the intended purpose. An example can be extracted from the current practices of some interviewed companies who reported measuring workers' satisfaction once a month using surveys where they could evaluate from 7 to 9 aspects of their work conditions. The frequency of the measures and the period when they were reviewed allowed projects to improve their performance during their development.

The third aspect to consider is the number of effects covered by the measurement system. The complete set of indicators should contain indicators assessing various of the effects mentioned in model. Although the continuous monitoring is focused on one or two indicators, it is also important to assess the performance of other effects. This can help to identify shortcomings or collateral results influencing other areas, positive or negatively. This aspect can observed in the evaluation worksheet that will be presented next, and it divides the evaluation in four areas, each of them containing a number of the different effects experienced (see Appendix A).

The final advice about the indicators is that it should be avoided the attempt to rely exclusively in very accurate quantitative data. Sometimes, the collection of 'soft' data or indirect measurement of indicators can provide very useful data that could not be collected otherwise. For example, measuring the impact of the weather on project performance is not an easy question but still can have a significant impact. Thus, quantifying the number of days with bad weather or extreme bad weather according to some pre-established parameters (i.e. $<-5^0$C, >3mm rain/snow, etc.) could be a helpful first approach.

The most important conclusion about indicators is that they need to have meaning and sometimes measuring a specific aspect is not a good indicator itself but applying further analytical tools can be transformed in the KPI to be monitored. Moreover, indicators should be balanced according to the criteria described above, for which it is required an iterative process before the final set of indicators is agreed.

Evaluation Worksheet

One of the aspects with greater consensus about the desired characteristics of the performance measurement system is possibility of benchmarking between projects. The answer for this wish from the industry is proposed as an evaluation framework where several metrics from projects are included while balancing their relative importance. Appendix A contains a first proposal of an evaluation worksheet that could allow direct project comparison. Appendix B shows an example of the use of the evaluation worksheet after being presented to practitioners.

It should be emphasized that what this evaluation worksheet tries to show is not a specific template to be used in every organization, rather an example of a method that brings benchmarking possibilities. Therefore, what is important in the evaluation worksheet is the idea of having a formal evaluation process that contains a set of defined project indicators common to all projects covering a wide range of measures. Moreover, this evaluation worksheet does not exclude the previously mentioned monitoring of indicators along the project, with their respective frequency and review period defined.

As seen in the interviews and confirming Andersen et al. (2011) previous studies, current project evaluation is very focused on costs as main factor, while other metrics such as schedule accomplishment, quality or other HSE factors are less valued if at all considered at project evaluation. According to performance measurement literature, measures reflected in this evaluation is what actually drives the behaviour of project managers and therefore is important to adapt this activity to strategic purposes. For example, if project managers know that the evaluation relies only in costs, they will manage the project to be sure of meeting the budget constraints, although this could threaten the schedule or quality accomplishments that otherwise could have greater impact on customer's satisfaction.

Organizations would need to spend some resources establishing the evaluation worksheet, since it should be maintained in the long term. Changing the evaluation worksheet would mean losing partially the ability to compare previous results. For this reason is important to have an initial period for testing the evaluation method accepting several iterations. Besides a specific period for the testing phase should be established beforehand to not extend indefinitely the implementation of the measurement system, as well as the idea of reaching a 100% perfect measurement system should be discarded. It should be acknowledged that the system would require an update after a certain time. Having an excessively static evaluation method is also a significant threaten to an effective measurement system (Melnyk et al., 2014). Considering the risks on both sides, it can be concluded that the validity horizon of the measurement system should be aligned with the validity horizon of the strategy. Shorter evaluation sessions can be programmed although the modification of the evaluation parameters need to be a carefully considered option.

The evaluation framework proposed here consider four areas of assessment: core project metrics, customer metrics, workers metrics and environmental metrics. Each of these

areas would have a determined weight in the global score according to organization's priorities. The worksheet contains basic elements for project identification and project manager responsible, and scores on each areas that should be added to obtain the total score of the project. Appendix B shows a practical example of how the worksheet should be filled, indicating in the black colour the information that is common to all projects such as indicators and relative importance, while the data that the project manager should fill is indicated in blue. Moreover, the formulas used are presented showing an aggregation method that would result in a score of 100 when all the expectations and predictions are satisfied, a giving above 100 when expectations are overachieved according to the balancing values (importance column). This enables internal benchmarking, although external comparison of projects is limited.

Furthermore, the values from metrics in each area should be used as a percentage or increment in order to have dimensionless magnitudes that allow comparison between projects of different sizes. For this reason, each metric has a column for the dimensionless value (rate), another column to define the relative importance of that metric over the whole assessment (import.), and the last column for the final score of the metric (value). Other aggregation methods for indicators have been used before in project evaluation methods (Berrah & Clivillé, 2007; Marques, Gourc, & Lauras, 2011) and applying these to the present framework constitutes an area for further research. Following are further explained the assessment areas.

Core project metrics contains the most common aspects currently used in the evaluation of projects such as schedule, cost, quality or HSE aspects. It would be wise to include in this assessment area the KPI chosen as reference to be monitored. The example provided in the Appendix A contains in this area the average PPC value together with its root reasons and the strategic alignment of the project.

The next assessment area is customer metrics. This area is expected to be filled in the early phases of the project and it should contain the specific expectations of the final user, often represented by the project owner. For obvious reasons is not possible to fill this area in advance by the organization since they most likely have a wide portfolio of customers with different needs and strategies. The score here could be obtained from a standard survey to measure customer satisfaction.

Worker metrics assessment have a wide range of possibilities to be measured and each organization would need to find their best way according to their own measurement culture. The only advice from the interviews is not measuring individuals' performance and keep measures at team level to avoid hanging one worker and create negative perception towards the measurement system. The worksheet proposed reflects how it would be in case of assessing worker satisfaction with a regular survey where they have to evaluate different aspects from 1 to 7. The total scores in the project could be collected in the evaluation worksheet and even weight their relevance for the final score.

Finally, environmental metrics are aimed to provide information about specific circumstances that could affect the development of the project. These events often make difficult to assess whether the improvement in projects come from the application of specific practices or are the result of better external conditions. Some could criticize the accuracy of these data and the extent to which projects are affected. However, should be considered the difficulty of measuring the data and the actual costs that could have if at all possible. Thus is advised to have an approach of 'good enough' measures to make easier the implementation of the performance measurement system while maintaining its validity.

An example of this type of measures is the weather, as showed in the evaluation document. It is clear that extreme weather affect the working conditions, especially in construction and especially in Norway. Establishing some thresholds value for temperature, rain or snow can facilitate the inclusion of its impact on the project. Obviously, employees still work behind those thresholds, but it is also clear that they would need breaks more often or require more time for the same tasks. Other aspects, such as changes should also be considered in context, since they may respond to repair mistakes or added value for the customer. Both should be considered as having impact on project metrics, but with opposite result in the final score. Olsson (2006) proposed a specific framework that could be very useful when analysing flexibility issues in projects. In this case, changes in the project are considered under a stakeholder's perspective, being flexibility when is the owner who is asking for these changes, and re-work when is on project's responsibility.

The last aspect to be mentioned is the formatting of the evaluation worksheet. Although this evaluation is shown in paper, this kind of evaluation would be better suited for its use integrated in the IT system of the company. The interview with practitioners shown that the current system of the company could admit to a large extent this type of evaluation. The advantages of using IT systems are obvious and it would allow managing data collection, access and security, and the reporting capabilities could generate this document. Further discussion of the most appropriate system is out of the scope of this thesis although is an important part to be considered when implementing the system.

Further comments received when presenting the model to research and practitioners are mostly focused on the metrics used in the evaluation worksheet. It was appreciated the inclusion of metrics not directly under control of the management to evaluate project success and allow comparing projects. It was shown special interest to include not only weather issues, but also nature-related aspects as unforeseen characteristics of the soil or the appearance of groundwater. Another aspect that was considered relevant to be included in the evaluation is to assess the quality of construction, or in words of the building's project manager when the construction is '*better built'* (author's translation from the interview in Norwegian, Interview 8). This characteristic was defined by the interviewees as the performance on the energy impact assessment (EIA) and the quality in terms of warranty repairs. As mentioned before, the evaluation worksheet presented does not pretend to provide a defined set of indicators to be used, rather a guideline on a wide perspective in evaluation methods. For this reason, only Appendix B shows the adaptation of the indicators mentioned.

Summarizing, the key aspect of this framework is extending the scope of the evaluation of projects further than just cost or time. Evaluation of projects is the way organizations have to tell project managers in what aspects they should focus, and it is of course a performance measurement system even if it is not being considered as such. When this fact is acknowledged, the evaluation can be utilized in the direction to help the company to achieve its goals.

The Roadmap of Performance Measurement in Lean implementation

Now that all the elements of the performance measurement model has been described in detail, this section will try to give a general overview of the process linking the different elements of the system. Hence, the aim is not to provide a full description of the Lean Performance Measurement implementation process, but showing the link between the different elements of the system. This will be shown in a number of steps following the logic of the model.

Step 1: Speed Up projects as part of the strategy

Independently if the company has carried out already some attempts in implementing Lean, the first question to address is whether the organization's strategy would require the implementation of Lean. The situation when the implementation of Lean would be highly recommended is if the company's strategy contains elements indicating an effort in reducing the completion time of projects. This state is the initial reference for the model.

It has been found a common practice from the interviews (Interview 2), and also reported in G. Ballard et al. (2007), the use of some demonstration projects after basic training is provided in order to learn how to apply Lean principles. These pilot projects could provide valuable information about which effect the organization want to focus on in the future, and they serve as a tool to gain the engagement of the top-management.

Step 2: Map the objectives that will allow achieving the strategy

Once the organization have in place the strategy related to speed up projects, some specific goals must be identified as part of the top-down approach. These goals should describe how to achieve the strategy, similarly to the Strategy Map from the Balanced Scorecard described in page 31. The model purposes three goals as the means to achieve the speed up of projects. The first goal is to have a design that is possible to be built on site and efficient in the construction process. The second goal is to have a plan that the project is able to follow and that will lead the speed up accomplishment. And the third goal is to avoid waste in the process in any of its faces (TIMWOOD, as previously

explained in this chapter). The goals here described are basic elements for achieving the strategy, although each organization could include more aspects from their organizational-specific perspective.

Step 3: Facilitate the identified enablers

When the objectives structure is in place, it should start the bottom-up approach, requiring facilitating the enablers mentioned in the model. From the top-down approach, the first enabler would only need following up of the implementation from top-management level, which is mostly ensured once it is part of business's strategy. The next enablers, motivation and competence should be provided to the whole project team. Practical training showing how Lean practices would work has been reported as a very positive experience for this purpose. Involvement of actors has been identified as the last enabler, which would include the participation of everyone involved in Lean practices in the process of acquiring motivation and competence, as well as deploying the practices. Additionally, identifying organizational-specific barriers and eliminating these obstacles, especially those exposed in the previous chapter, can be an important part of the facilitation process.

Step 4: Identify the effects to pursue

At this point all the basic elements for implementing Lean have been covered and it starts the actual process of adopting practices. Figure 11 (previously presented in page 118) shows the relation between the most common Lean practices and the direct effects that can be expected. There are two possible perspectives: having already implemented some Lean practices so the need is to measure effects, or having some effects as objectives and Lean practices need to be selected. In any case, at the end of this stage it should be clear for the organization what practices to apply and which effects are prioritized.

Step 5: Generate a balanced set of KPIs

Given the effects that the organization pursue to improve, a balanced set of KPIs should be selected together with the frequency of measurement and period for reviewing performance according to their purpose. Following is a group of characteristics that could be used as a checklist for the definition of key performance indicators.

- Each indicator serve a specific purpose or purposes linked to the effects pursued
- Well distributed presence of past-, present-, and future-focused indicators (lagging vs. leading indicators)
- Monitoring frequency of data collection and reviews period according to its purpose
- All the effects pursued are represented in the KPIs
- Presence of both soft and hard measures

Step 6: Generate the Evaluation Worksheet

These KPIs should be translated to an evaluation worksheet, which could be built up within the IT systems of the company as part of the project evaluation process. It should be distinguished two parts in the performance measurement system. On one side, the continuous monitoring of the projects which allows corrective action. The information systems of the company should provide the tools for the collection, analysis and distribution of data according to the defined needs from the KPIs. On the other side, the evaluation worksheet collects the final results of the indicators monitored along the project and additional specific measures for its evaluation.

Using a specific framework for project evaluation have a number of benefits. First, it makes wider the scope of project evaluation, promoting better practices among project managers according to organization's strategy. The evaluation worksheet could serve as a tool for the standardization of processes in the 'Lean Journey' (G. Ballard et al., 2007). Second, it provides a base for assessing the impact of Lean practices in projects, as well as circumstantial factors. Finally, it allows benchmarking of projects, which can provide direction for improvement and further development of strategy.

Step 7: Further work

The scope of the thesis is limited to the study of how the effects of Lean practices can be measured, and therefore the actual implementation within organizations has not been covered. However, there are some aspects that should be acknowledged.

The purpose of the performance measurement system presented is to support the implementation process of Lean practices. Andersen and Fagerhaug (2002) described the implementation process of a performance measurement system, which includes in the last steps the design of reporting and presenting formats (covered to a certain extent in the current thesis), testing and adjusting the system and the actual implementation for its use within the organization. This includes the need of evolving the system once an acceptable level of implementation is achieved or reviewing it in case new challenges are identified. Further references about the implementation process can be found in the literature presented in Chapter 4 (see page 67).

The presented roadmap collects the most significant elements of the performance measurement model created for supporting the implementation of Lean practices in the construction industry. In addition, as a purpose-specific framework it might be deployed together with other KPIs for different aspects of the global strategy of the organization. The model presented is a first attempt to cover certain needs identified in the industry, although further work is needed to test the model in practice and adapt the possible deficiencies.

Chapter 8:

Conclusions and Further Research

This chapter includes the conclusion notes of the present thesis by pointing at the key findings and contributions according to the original purpose, as well as recognizing their limitations and purposing paths for future research in the areas covered.

Conclusions

The construction industry in Norway has carried out during the last decade a number of efforts in the implementation of Lean practices. The practices in which the organizations are focused vary as well as the level of implementation and results obtained, but with the exception of certain companies the implementation is still limited and so the results obtained.

The use of performance measurement systems to drive the improvement of processes and the recent interest from the industry in these tools provide a sound foundation for the use of these frameworks in conjunction with Lean practices. The general trend among performance measurement frameworks presented in the literature during the last years, as well as the evolution of success factors in construction projects, indicate that purpose-specific measurement models can be a meaningful solution for supporting the implementation of Lean.

The purpose of the thesis has been to gain insight into how Lean practices are applied in the construction industry and examine the performance measurement systems that could contribute to their successful implementation. Several research questions were defined to frame the study.

1. *What performance improvement attempts are construction companies carrying on?*

Among the Lean practices, the one that have been found more often in the companies is the Last Planner, which adoption within the companies take different names, usually referring to involving planning. Although it is not being implemented to a full extent according to the original theory by G. Ballard et al. (2007), companies have realized some improvements by adapting the practices to their needs. The use of Pull Scheduling, often part of the Last Planner system, is less extended and traditional methods for the planning are still predominant. However, those projects who have used this practice acknowledge its potential for reducing the project's completion time and its use is further encouraged. The key factor for the implementation in practice was having received specific training on those practices to make project participants confident in their use.

Another practice that has a strong presence is Concurrent Engineering, although similarly to other practices is often not implemented to a full extent. According to the literature and the practitioners' perspective, Concurrent Engineering can be considered under the principles of Lean. Nevertheless, its implementation could be focused on maximizing concurrency rather than a general Lean approach. The use of Concurrent Engineering in practice is often associated with the use of Virtual Design Construction tools and more specifically having concurrent meetings although these are focused on the execution phase as a problem-solving tool.

When assessing the extent to which these practices were being implemented, the result is widespread. While some companies have adopted a strategic perspective in the use of Lean encouraging its implementation in every project, other companies lack of such experience and adopt these practices only in the cases where is strictly needed due to time constraints. This makes necessarily a difference in terms of organizational learning about the use of Lean, although this can be considered only as a consequence of the implementation stage of Lean. Hence it could be expected that the use of Lean practices

is extended in the future once companies realize the benefits obtained both internally and throughout the subcontractors.

Together with the practices itself, other aspects have been discussed in order to have a wider perspective of the current situation. It has been found that the workers played a fundamental role in the deployment of Lean practices, either because of the company is willing to improve their labour conditions, because they were claiming improvements in the planning process or because it was employees' initiative to use certain practices. Although this is a significant fact, practitioners agreed on the need of having a top-down approach for the successful implementation of practices. In other cases, time constraints in projects motivated the use of Lean practices.

Another aspect that has been considered analysing the use of Lean practices in the construction industry has been the practitioners' perspective on Lean. This resulted in a Lean model (Figure 8) based on the figurative idea of a train with each coach representing the activities required for the construction, so the train moves simultaneously through the construction site until the building is completed. Furthermore, it emphasizes the need of extensive involvement of actors and provide the required training. The practices described together with the other use-related issues and the model expressing the practitioner's perspective of the Lean practices represents a clear picture of the performance improvement attempts in the construction industry.

2. *What are the effects of these practices in project performance?*

Further analysis was focused on the actual benefits that the companies were obtaining in Lean projects and the difficulties found over the implementation process. The aim was to find which areas have obtained greater benefits derived from the use of Lean practices as well as the success factors for achieving those benefits.

The first result to be mentioned is the reduction of projects' completion time, which has been mentioned for every project during the interviews with severe reductions in some cases. The improvement of quality has been commonly mentioned, especially referring to building with less mistakes and having less items in the pending work list after delivery of the product. The interviews for assessing the model indicated also improvement in the warranty costs and better results in the energy impact assessment. Completing the iron

triangle, costs are usually not one of the first characteristics to improve due to the need of training and consultancy which costs were allocated within the budget of the projects. Thus it can be expected greater improvement in costs when the amount of training and consultants are reduced as a consequence of the learning curve.

The aspect that probably has achieved greater improvement after completion time is predictability. This is translated in project owner's ability to determine precisely the termination date and optimize the management of their facilities. At the same time, workers' improved their ability to assess whether they will be able to perform their tasks considering minor injuries, which reduces the absence rate.

The impact of Lean practices in workers satisfaction is the third key improvement experienced. This aspect is related to other collateral issues, such as improved cooperation, better defined responsibilities, less fights during the projects, greater commitment to the plan, among others. Even though some projects required working overtime, the freely commitment from the workers made that still the satisfaction at the completion of the project was very positive as they would accept working using those methods over longer periods of time obviously excepting the use of overtime.

These effects can be validated from Lean literature as demonstrated in Andersen et al. (2012) and Salem et al. (2006).

3. *What are the stakeholders' needs in the implementation process?*

In addition to the Lean practices and its effects in projects, a stakeholder analysis was performed in order to further analyse the participation of the stakeholders in the implementation and their needs for increasing their involvement to the expected level. The result of this analysis is the stakeholders' needs model presented in Figure 9.

The stakeholders' needs model indicate three basic needs for the implementation process of Lean, which are in accordance with the findings from Bakås et al. (2011). Additionally, the model links the specified needs to the different stakeholders in the construction industry revealing who has the need and which stakeholder could provide the sufficient coverage.

The first basic need is strategic decisions from top management and owners in order to provide guidance to project managers in the decision making process. Second, employees participating in the projects, from managers to subcontractors, would need to acquire the competence necessary to know how to apply the practices, and the motivation from the convincement of its benefits for the effective use of those practices. Based on the metal models from Senge (2014) and aligned with the findings from Kim and Park (2006), it can be argued that providing practical training could enable both competence and motivation. Finally, the ability to measure results could facilitate making strategic decisions towards the implementation of Lean practices and it would allow project managers driving the projects successfully while applying these practices.

From the expressed need of measuring results is rooted the motivation for creating a performance evaluation system specific for its use in the context of implementing Lean in construction companies, which could leverage the accomplishment of the expected benefits.

4. *How can these effects be measured (in order to support the fully implementation of those practices)?*

The proposal for measuring the effects derived from the use of Lean practices is defined in the performance measurement model expressed in Figure 10. As explained in The Roadmap of Performance Measurement in Lean implementation (page 127), the model contains two approaches.

The top-down approach starts with the creating of a strategy towards reducing the completion time of projects, being further developed through three goals. The first goal is having a reliable design that can be built with fidelity in the construction site. Second, having a reliable plan that the workers are able to meet and that brings the time accomplishments, and thirdly reducing waste through any of the possible faces (transport, inventory, motion, waiting, over-processing, overproduction and defects).

Following is the bottom-up approach, which is shaped by the enablers extracted from the stakeholders' needs model. These enablers include the support from top-management in form of guidance and following up of the implementation process, motivation and competence from project's participants and involvement of all relevant actors.

The model then facilitate the identification of effects that each company could pursue according to their status in the implementation process, and then a balanced set of key performance indicators should be generated according to their purpose, time-focus, frequency and reviewing period of the measure and the use of both hard and soft measures. Extensive literature review of indicators used in the construction industry as well as success factors in projects aims to support the generation process of KPIs (Table 3, Table 4).

Additionally to the generation of KPIs for supporting the implementation of Lean practices, the model purposes an Evaluation Worksheet which is intended for enabling benchmarking between projects. This tool should adapted by the organization according to their priorities, serving as a framework for an extended project evaluation. The organization should decide internally in what metrics they should base the evaluation of projects and the relative importance of each metric in the final score. Four general areas are purposed to be included. General project metrics around the iron triangle (cost, time and quality), customer metrics, worker metrics (related to HSE), and environmental metrics including factors out of the control of the management that could impact the project outcomes.

The main contribution of the evaluation worksheet further than allowing project benchmarking is the inclusion of the external factors in the evaluation. This enables to assess whether the improvement in the performance came from the implemented practices or was the coincidence of other factors, which was one of the main claims from practitioners.

Although the study of the latter implementation of this model is out of the scope of the thesis, the criticality of this aspect in the success of the performance measurement systems enforces the literature review of these issues (

Organizational change, page 67).

All in all, the thesis provides a general overview of the use of Lean practices in the construction industry and accounts for the benefits obtained as a result of their implementation. Furthermore, it looks at the needs for improving the implementation under a stakeholders' perspective and provides a framework for the effective implementation of Lean practices as well as enables the measurements of its results.

The novelty of the framework considering together Lean practices and Performance Measurement systems is one of the greatest contributions of thesis. The stakeholder perspective in the study of the needs in the Lean implementation process is another of the innovations. The inclusion of external factors in project evaluation has been rarely considered previously and is third aspect containing the foremost originality of the thesis.

Limitations and further work

Although the results of the thesis have shown relevance and utility throughout the interviews for assessing the model with researchers and practitioners, there is also a number of limitations that should be acknowledged.

The first limitation regards the methodology used to obtain the results. Qualitative research and the use of semi-structured interviews to obtain the data is susceptible to criticism from relying on subjective interpretation of data. The same research could have reached different results from other authors. This limitation is mitigated by contrasting the findings with relevant literature in similar contexts, showing a significant degree of alignment.

Another limitation resulting from the methodology is the restricted ability to evaluate the relationship among the expected effects. The lack of data quantifying the effects and the reduced number (four) of data collection interviews limited the generalization of results and the study of correlation between the elements object of study. These relationships have been partly reflected in the analysis whereas these interactions could have a significant impact in the implementation process of Lean as well as for establishing the performance measurement system. Further research in this area could make possible simplifying the model and identifying specific effects that could trigger further benefits in collateral areas.

Similarly, the present study does not quantify the expected results, which could result in some of the effects not being significant for the project's performance. However, the confessed difficulty on measuring effects enforced the study to acquire data from interviews. Therefore, future research could assess the significance of the effects,

although it might be necessary to implement first the measurement model in order to generate the necessary data.

The companies participating in the interviews belong to a specific context that is the construction industry in Norway. The applicability of the model to other contexts should be examined to ensure its validity, and it represents an area for further research. Moreover, the study has not been limited to a specific type of projects although there can be significant differences depending on the type of construction. Extending the study including a set of different type of projects could improve the assessment of the applicability of the model.

Further research could also include the development of specific key performance indicators to be used according to the type of project, the generation of an implementation process including guidelines about how to test, adjust and review the measurement system and even the practical implementation of the measurement model in projects. Additionally, aggregation methods for balancing the importance of indicators could be applied to the evaluation system.

Other perspectives from Lean implementation could add significant insight on the success factors. For example, focusing on organizational behaviour could examine in more detail the motivation of people adopting Lean practices. Moreover, studying the role of performance measurement systems in dealing with uncertainty management can have a significant impact when measuring and implementing Lean, especially in case of considering the degree of projects' complexity.

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Appendix A:

Evaluation Worksheet

EVALUATION WORKSHEET

Project ID		Project Manager	

	Attributes	Goal	Actual	Rate	Import.	Value
Project metrics	Completion time					
	Budget					
	Average PPC					
	Root reasons* (5-WHYs, Pareto principle)					
	Strategy alignment					
					P Score	

*Allocation of responsibilities, actor's involvement, TIMWOOD

	Key Customer Requirements	Accomplishment
Customer metrics		
		C Score

	Attributes	Goal	Actual	Import.	Value
Worker metrics	Safety				
	Predictability				
	Internal collaboration				
	External collaboration				
	Tidiness				
	Absence rate				
				W Score	

	Attributes		Units	Rate	Import.	Value
Environment metrics	Weather (days)	< -5^{0}C				
		>3 mm rain				
		>30ºC				
	Changes (man-hours)	Flexibility				
		Re-work				
	Additional complexity on site	Man-hours				
					E Score	

Project	
Customer	
Worker	
Environment	
TOTAL SCORE:	

Appendix B:

Example of Use of the Evaluation Worksheet

EVALUATION WORKSHEET

Project ID	B1-1987-11-13-N	Project Manager	Kari Nordman

	Attributes	Goal	Actual	Rate	Import.	Value
Project metrics	Completion time	36 months	32.5 months	1.0972	20	21.94
	Budget	980 M NOK	1030 M NOK	0.9490	15	14.23
	Average PPC	0.85	0.89	0.9529	10	9.52
	Root reasons* (5-WHYs, Pareto principle)	- Not communicated schedule - Moving heavy tools				
	Warranty cost per m^2	100 NOK/m^2	108 NOK/m^2	0.9200	5	4.6
					P Score	**50.31**

*Allocation of responsibilities, actor's involvement, TIMWOOD

	Key Customer Requirements	Reached expectations	Result*	Import.	Value
Customer metrics	Predictable completion time	10 (Overachieved)	1.2	6	7.2
	Predictable results (product)	8 (Achieved)	1	6	6
	Low energy consumption in use	7 (Acceptable)	0.9	6	5.4
				C Score	**18.6**

*This can be a tabulated value from the results of a survey.

	Attributes	Goal	Actual	Rate	Import.	Value
HSE metrics	Safety	6	6.0	1	8	8
	Predictability	6	5.9	1.0667	1	1.02
	Internal collaboration	6	6.2	0.9667	1	0.97
	External collaboration	6	5.6	1.0667	1	1.07
	Tidiness	6	6.1	0.9833	1	0.98
	Absence rate	0.04	0.054	0.65	4	2.6
	EIA	B	B	1	6	6
					W Score	**20.63**

	Attributes		Units	Rate	Import.	Value
Environment metrics	Weather (days)	< -5^{0}C	32	1.2*	1	1.2
		>3 mm rain	25	1.1*	1	1.1
		>30ºC	2	1*	1	1
	Changes (% man-hours)	Flexibility	1.34	1.26	4	5.36
		Re-work	1.08			
	Additional complexity on site	% Man-hours	1.03	1.03	3	3.09
					E Score	**11.65**

*This can be a tabulated value according to statistics

Project	50.31
Customer	18.6
HSE	20.63
Environment	11.65
TOTAL SCORE:	**101.2**

EVALUATION WORKSHEET

Project ID	B1-1987-11-13-N	Project Manager	Kari Nordman

	Attributes	Goal	Actual	Rate	Import.	Value
Project metrics	Completion time	36 months	32.5 months	$= 1 + \frac{G - A}{G}$	20	$= R * I$
	Budget	980 M NOK	1030 M NOK	$= 1 + \frac{G - A}{G}$	15	$= R * I$
	Average PPC	0.85	0.89	$= 1 + \frac{G - A}{G}$	10	$= R * I$
	Root reasons* (5-WHYs, Pareto principle)	- Not communicated schedule - Moving heavy tools				
	Warranty cost per m^2	100 NOK/m^2	108 NOK/m^2	$= 1 + \frac{G - A}{G}$	5	$= R * I$
					P Score	$= \sum V$

*Allocation of responsibilities, actor's involvement, TIMWOOD

	Key Customer Requirements	Reached expectations	Result*	Import.	Value
Customer metrics	Predictable completion time	10 (Overachieved)	#	6	$= R * I$
	Predictable results (product)	8 (Achieved)	#	6	$= R * I$
	Low energy consumption in use	7 (Acceptable)	#	6	$= R * I$
				C Score	$= \sum V$

*This can be a tabulated value from the results of a survey.

	Attributes	Goal	Actual	Rate	Import.	Value
HSE metrics	Safety	6/7	6.0	$= 1 + \frac{G - A}{G}$	8	$= R * I$
	Predictability	6/7	5.9	$= 1 + \frac{G - A}{G}$	1	$= R * I$
	Internal collaboration	6/7	6.2	$= 1 + \frac{G - A}{G}$	1	$= R * I$
	External collaboration	6/7	5.6	$= 1 + \frac{G - A}{G}$	1	$= R * I$
	Tidiness	6/7	6.1	$= 1 + \frac{G - A}{G}$	1	$= R * I$
	Absence rate	0.04	0.054	$= 1 + \frac{G - A}{G}$	4	$= R * I$
	EIA	B	B	#*	6	$= R * I$
					W Score	$= \sum V$

*Tabulated value according to results from EIA

	Attributes		Units	Rate	Import.	Value
Environment metrics	Weather (days)	< -5^{0}C	32	#*	1	$= R * I$
		>3 mm rain	25	#*	1	$= R * I$
		>30ºC	2	#*	1	$= R * I$
	Changes (% man-hours)	Flexibility	1.34	$= Uflex$	4	$= R * I$
		Re-work	1.08	$- Urework$		
	Additional complexity on site	% Man-hours	1.03	$= U$	3	$= R * I$
					E Score	$= \sum V$

*This can be a tabulated value according to statistics

Project	# P Score
Customer	# C Score
HSE	# W Score
Environment	# E Score
TOTAL SCORE:	$= \sum Scores$

Appendix C:

Interview Guide

Interview guide

Objectives:

- To know how improvement attempts (Lean/Concurrent Engineering) are being used in the company. For how long has been used and how is currently used with some examples.
- To know the barriers that the company is facing for the implementation of Lean.
- To know what is important at different levels of the organization to implement Lean.
- To know what are the projects' success factors and how they are being measured.
- To know if they have a performance measurement system or other kind of quality management system.

Variables:

Independent variables, (those responsible to bringing change)

- Where the motivation for Lean comes from (employees, project managers, top management, project owner, project office, competitors, other)
- Level of awareness of Lean among employees (none, basic –theoretical knowledge-, beginner – first project-, and experienced –at least one project completed-)

Dependent variables, (these are the effects of a change in a dependant variable)

- Degree of involvement of stakeholders on Lean
- Performance measurement effects

Interview Structure:

A. General presentation

Introduce yourself, what is your position within the company? What is your previous experience? Explain briefly the years of experience in each position.

What is the main activity of your business? (e.g. Design, construction, both design and construction)

B. Experience with Lean

Can you give a brief definition of lean construction and the principles that make up lean?

When did the company start using Lean? What was the motivation of the company for implementing Lean? Where did the initiative come from? (top management, project managers, other employees, …)

Is Lean implemented overall as a company or is it more project-specific or on some specific processes only?

0.1 If project Specific, How you choose the project for lean implementation (based on size, cost, contractual requirement)?

0.2 If company wise, to which processes you have implemented lean? (e.g. designing, logistics, constructing)

Who is involved in the deployment of Lean? (Both internal and external actors)

To what extent do these actors apply Lean? How do they apply Lean? Give some examples.

Did the company provided training about Lean? What does the training consist of and what people were involved?

Did the company use any parallel tool when implementing Lean? (Just in Time, Last Planner, Concurrent Engineering, BIM, etc.)

How long did it take to implement lean construction?

C. Benefits from Lean Implementation

Does the company have any target for improving performance when introducing Lean? What is the target? Has the company met the expectations regarding Lean?

What are the key improvements that the company has achieved with Lean?

What impact have the implementation of Lean on factors like time, cost and quality?

Please identify the social, economic and the environmental benefits of the lean approach in your organization if any

D. Barriers and Success Factors for Implementation of Lean

What are the difficulties that the company is facing to meet expectations?

What are the barriers that the company has already overcome?

What aspects is the company focusing on to continue the improvement?

What was the success factors encountered?

How would you advice a potential company wishing to implement lean construction?

E. Project Performance

What are the success factors in projects?

Do you measure performance?

What are the metrics in projects? (time, cost, safety…)

How do you measure performance? When do you measure?

Is there any difference in the measurement between a project using Lean and other not doing so?

How are projects evaluated after completion?

Does the company has a quality system for assessing performance? (KPIs, etc.)

The following table is aimed to give stakeholder's perspective on Lean practices. We kindly ask you fill the table according to the different levels described. (for second column, 1 means no interested, 2 interested but not actively involved, 3 reluctant with low active participation, 4 active involvement, 5 active involvement inviting more actors to participate.)

Stakeholder level	Level of involvement in Lean (1-5)	What do they do towards Lean? How are they involved? (f.ex. in what initiatives are they involved)	What do they need to improve involvement? (what would leverage their participation in initiatives)
Industry as a whole in Norway			
Top management			
Project level			
Employees			
Subcontractors			
Users (or on their behalf -owner-)			

F. Measurement system

Rank the following aspects of a hypothetical measurement system:

- Ability to implement strategy
- Possibility of comparing projects (benchmarking)

- Ability to measure specific initiatives
- Ability to measure general project performance

- Focus on internal performance
- Focus on value chain performance

- Centred on management
- Centred on users
- Centred on employees and subcontractors

- Ability to provide performance of each employee (personal goals)
- Ability to provide feedback on team's performance
- Ability to provide feedback on project performance

- Ability to provide information during the development of the project
- Ability to provide information at the closure of the project

- Integrated in the current company's information system.
- Include new features better suited to show performance measurement

- If any (respondent suggestions)

G. What question would you ask yourself? Missing key points.