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A Supplier-Oriented LPS Framework

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Preface

The following thesis is submitted as part of the TPK4930 production management master thesis in the Department of Production and Quality Engineering at NTNU. This thesis is part of the program components in the fourth semester and gives 30 credits. The master thesis supports the LIFT research project at the innovation level of integrated planning process in the Norwegian heavy lifting industry value chain. LIFT is a collaboration between two research institutions and several industry partners, where the main goal is to improve engineer-to-order project planning and control practices. LIFT is funded by the Norwegian Research Council.

The master thesis was written under the guidance of the Associate Professor Erlend Alfnes and PhD candidate Gabriele H. Jünge, both from the Department of Production and Quality Engineering at NTNU. We would like to thank them both for their help and understanding approach. The authors would also like to express their appreciation to the case companies participated in this study. Without their contribution, this paper would have never been materialized.

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Summary

The engineer-to-order (ETO) sector is characterised with a combination of both uncertainty and a wide range of interdependencies between the different entities, especially due to the disintegration of engineering and production. Such characteristics pinpoint the high level of complexity in such sector, which consequently increases the coordination effort required in order to successfully manage an ETO supply chain (SC). In fact, previous literature has shown how the ability to coordinate internal and external processes arises as a challenging necessity for competitive advantage in an ETO SC. Consequently, improving performance in an ETO SC is very much related to the ability to improve engineering and production activities in regards to coordination.

The main intention behind coordination should be to align plans and objectives of individual participants. In regards to complex environments such as ETO, theory suggests how the coordination effort should not be minimized by isolating interdependent functions. However, in order to address effective solutions to the problematic nature of coordination, the different factors affecting coordination need to be better understood.

Five factors affecting coordination were identified during the master thesis, including: high level of uncertainty, overlapping engineering and production, maturity of the design technology, geographic dispersion and production capability. It can be concluded that such factors arise due to the overall characteristics of the ETO environment. In other words, such factors are not necessarily avoidable, showcasing the number of challenges which need to be handled throughout an ETO project. Several coordination mechanisms have been suggested in regards to the engineering and production interface and should be matched with the coordination effort needed. However, less focus has been dedicated to how such mechanisms can be implemented and utilized in practice.

The planning process in ETO organizations is considered as a core capability and is consequently an important source for competitive advantage appointed to be the mean to emanate the required coordination mechanisms in the ETO project context. The collaborative planning and control method in the Last Planner System (LPS) has demonstrated coordination improvement in several ETO construction projects around the globe. LPS has a strong focus on achieving a good flow between project units, leaving behind the optimizations for increasing the efficiencies of each individual project unit. The fact that the ETO sector shares to some degree the same peculiarities and consequently many of the same challenges as the construction industry, opens the possibility to adapt tools, approaches and methods from one industry to another.

A conducted analysis enlightened the feature of LPS to structure the coordination mechanisms in practice. Areas of opportunities were identified, where most of the required improvements relates to the involvement of suppliers and their specific participation throughout the project. Specific tasks which can increase the competitive edge due to the coordination effects these activities generate have been suggested by theory. However, it has not been clear on how suppliers should be involved throughout the whole project development.

A supplier-oriented framework has been presented based on the union between the LPS stages and specific supplier involvement (SI) tasks with the objective of providing the best coordination effects between design/engineering and production, where *planning for* the supplier is left behind, superseded by *planning with* the supplier.

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Abbrevations

ETO	**E**ngineer **T**o **O**rder
SC	**S**upply **C**hain
SCM	**S**upply **C**hain **M**anagement
NPD	**N**ew **P**roduct **D**evelopment
SI	**S**upplier **I**nvolvement
DFM	**D**esign **F**or **M**anufacturing
CE	**C**oncurrent **E**ngineering
TPS	**T**oyota **P**roduction **S**ystem
PMI	**P**roject **M**anagement **I**nstitute
LCI	**L**ean **C**onstruction **I**nstitute
LPDS	**L**ean **P**roject **D**elivery **S**ystem
LPS	**L**ast **P**lanner **S**ystem
WWP	**W**eekly **W**ork **P**lan

"Alone we can do so little; together we can do so much"

Helen Keller

1 Introduction

The following chapter aims to give a general introduction to the topic and an overview of the motivation behind writing this master thesis. Background, problem description, objective and scope, research questions and methodology follows.

1.1 Background

Companies in all sectors are examining and utilising ways to reduce costs, shorten development times and manage risk. In order to do so, companies exercise supply chain management (SCM) (Hicks et al., 2000; Tommelein et al., 2008). In fact, SCM has enabled manufacturing companies to obtain competitive advantage by improving their overall performance. However, such research has mainly been focusing on the high-volume mass production sector (Bresnen, 1996; Amaro et al., 1999; Nishiguchi, 2004; Burgess et al., 2006), while limited research has been done regarding project based manufacturing within global supply chain (SC) networks (Hicks et al., 2000), such as for companies in the engineer-to-order (ETO) sector.

ETO companies are described based on their characteristics in terms of the market they operate in, type of product and the internal processes of their organization (Hicks et al., 2000). Preliminary, projects in the ETO sectors relate to the supply of a high variety of complex equipment to third parties in a non-repetitive environment through the phases: design, procurement, manufacturing, installation and commissioning (McGovern et al., 1999; Wortmann et al., 1997; Braiden et al., 1993) were the last three phases are usually outsourced (Hicks et al., 2000). Hence, product development normally involves multiple worldwide companies in an ETO SC (McGovern et al., 1999; Hicks et al., 2000).

Moreover, due to the distinct product and process characteristics, every SC is usually temporary (Tommelein et al., 2008). The effort to coordinate such temporary cross-business activities has become the most vital challenge and might jeopardize the potential gains of outsourcing (Lambert et al., 1998). In fact, delays, budget overruns, and quality defects have shown to be frequent outcomes of many projects (Hao et al., 2008). The fact that customers usually change their orders throughout a project (Bertrand and Muntslag, 1993), makes coordination between the entities even more challenging (Mentzer et al., 2001). A prerequisite for successfully delivering ETO projects then becomes to rapidly react to such changes (Little et al., 2000), meaning that the engineering, procurement, manufacturing, assembly and installation needs to be coordinated efficiently in an ETO SC. Hence, project management in ETO needs to be capable of synchronizing engineering and production planning.

1.2 Problem Statement

Manufacturing planning and control (MPC) refers to the planning and control of all aspects of manufacturing throughout the SC. Managing materials, scheduling machines and people, coordinating suppliers and key customers are examples of such planning and control (Jacobs et al., 2011). MPC provides key information for managers to make the most effective decisions. However, planning across non-hierarchical networks such as the ETO SC becomes especially challenging due to conflicting objectives and continuously changing demand. In such case, the challenges related to coordinating systems that do not fully share all relevant information between companies need to be encountered by planning and control (Alvarez, 2007). However, even though planning is considered the foremost beneficial factor for success (Laufer and Tucker, 1987), projects still overrun and insufficient planning is one of the main reasons for poor project performance (Oehmen, 2012; Kerzner, 2013b; Kjersem and Emblemsvåg, 2014). Consequently, there is a need for better planning methods that can assist the chaotic project environment (Little et al., 2000). Research has shown how project planning in manufacturing projects usually is reduced to Gantt charts (Sullivan, 1991). In other cases, there is no or low degree of standardization in the project planning process, poor performance measurement, and little or no collaboration between engineering and production (Emblemsvåg, 2014b; Junge et al., 2015). In fact, the importance of a more collaborative approach towards suppliers has become recognised as important in the low-volume sector due to the fact that a huge part of total contract value is handled by other entities (Dubois and Gadde, 2008). Nevertheless, research has shown how 'win-lose' transactions and mutual mistrust both are characteristics and consequently an outcome of multisourcing activities (Puto et al., 1985; McGovern et al., 1999). The motivation behind this master thesis is therefore related to the need for a planning and control method which is able to handle the chaotic ETO environment and consequently improve single project performance and ultimately company performance. Hence, the overall aim is to contribute to increase the understanding of how integrated planning and control between entities in a SC can overcome coordination challenges and consequently increase SC performance in one-off projects.

1.3 Objective and Scope

In order to attain the overall aim of this master thesis and guide the research, several objectives were defined. Objective 1 is related to identifying the factors affecting coordination between the entities in an ETO SC, while objective 2 is to highlight the potential of how coordination can be facilitated through a collaborative project planning and control method named Last Planner System (LPS). Objective 3 aims at identifying how both engineering and production should be involved in the process of project planning throughout the phases of a project. Finally, objective 4 is to conduct a multiple case study to identify how planning and control is conducted in two Norwegian ETO companies with the purpose of supporting the arguments presented in this master thesis. The four objectives are summarized in the following table 1.1:

Objective	Description
1.	Identify factors affecting coordination between entities in an ETO SC
2.	Highlight the potential of how coordination can be facilitated through LPS
3.	Identify how both engineering and production should be involved in the process of project planning
4.	Conduct a multiple case study to identify the planning and control situation in two Norwegian ETO companies

Table 1.1: Master thesis objectives

Due to the fact that a huge part of the total contract value is usually handled by other entities than the focal company (Dubois and Gadde, 2008), the scope of this master thesis is limited to coordination between engineering and the supplier responsible for production in a one-off project, where the engineering company is responsible for the overall project.

The master thesis supports the LIFT research project at the innovation level of integrated planning process in the Norwegian heavy lifting industry SC. A successful collaborative planning and control process in ETO SC would solve a critical problem firms have struggle with for a long time.

1.4 Research Questions

The master thesis will focus on answering the following research questions which are formulated to guide the research based on the overall aim and the objectives shown in table 1.1.

RQ1: What factors affect coordination in an ETO SC?

RQ2: How can LPS overcome the factors affecting coordination between entities in an ETO SC?

RQ3: How should suppliers responsible for production be involved in the planning process of LPS throughout a project?

2 | Methodology

Methodology is a systematic, theoretical analysis of the methods applied in a field study, contributing to answer a given research problem (Kothari, 1990). This chapter will thus, describe both the approach and the overall considerations made in this master thesis related to the logic behind the selection of the methods and techniques for collecting and analyzing data and establishing relationships.

2.1 Research context

In a broad sense, research can be seen as the gathering of data, information and facts for the advancement of knowledge. However it is argued that the what, why and how of research rarely derive single-handedly from literature. In other words, good research ideas are usually shaped due to a number of contextual factors, such as researcher's background and trends in the field of study (Easterby-Smith et al., 2002), this master thesis has been no exception.

2.1.1 Background and experience

The objective of this research has most definitely been influenced by the background of both master students. One has more than six years of experience from the construction industry before going further becoming an electro engineer, while the other has over three years of experience as a quality chief supervisor in the manufacturing sector following a bachelor degree in engineering. When a decision was made in regards to pursue the objective of receiving a master degree, both students wanted to increase their engineering expertise while at the same time ensure a 'red line' between the different stages of their education.

NTNU's *Departments of Production and Quality Engineering*, which works on the point of intersection between technology and management by offering a combination of courses in topics including strategy, industrial economics, production, logistics and technology management has offered both student an expansion in their engineering expertise and consequently the know-how before the start up of a master thesis. In regards to the choice of master thesis objective, both authors wanted to go further within a topic related to their background and future careers as engineers. The challenges of working together towards a common goal in highly uncertain environments is something both authors have experienced in their professional careers, and thus also the great potential for improvement. All this pointed towards a master thesis subject and objectives related to collaboration as an outcome of project planning.

Fields of study

Easterby-Smith et al. (2002) argue how current trends, fads and fashion in the academic discipline tend to influence the research issues, objectives and methods. As the research conducted in this master thesis lies at the interface between production planning and project planning, it has made the master students aware of how easily misunderstandings might occur between affiliated research units. This is the overall reason why the introduction to the overall theoretical study has been dedicated to define certain terms which have been used interchangeably in literature, in order to make a clear distinction and avoid possible misunderstandings.

2.1.2 Research strategy

Design science

As a research method, the design science paradigm has been receiving an increasing interest as an alternative approach. It has its origin in the first edition of 'The Sciences of the Artificial' (Simon, 1996), which was first published in 1969. It built on previous developments and motivated the development of systematic and formalized design methodologies contrasting the natural science and has been found effective to solve practical problems identified in industry (Hevner, 2007). As design science is prescription-driven, research in natural science is description-driven. The overall idea behind design science is to develop knowledge in order to solve problematic situations in reality with a focus on improvements in a preexisting system or in a system that does no yet exist, with an overall goal of improving the human condition. Hence, the outcome of design science research should strive for the improvement of situation as an outcome of improved design (Van-Aken and Romme, 2009). Given this purpose, the master thesis study will be designed and conducted under the design science paradigm.

2.1.3 Research design and process

The logic that links the data to be collected to the initial research questions is according to Yin (2009) referred to as research design. So in regards to achieve the master thesis research objectives (increasing knowledge on the ETO sector in regards to factors affecting coordination between engineering and production and LPS applicability to overcome such challenges), the researchers studied a large number of publications in order to assess the problem situation for investigating the applicability and develop guidelines based on this. The overall research process (main activities and outcomes/results) will be summarized in more detail in figure 2.1.

A process might be defined as a planned series of actions for the time required to bring about the desired reactions or results (APICS, 2013). However, Gill and Johnson (2010) argue that a research process is not necessarily as unambiguous due to the chaotic interactions between the conceptual and the empirical world. Hence, as a 'research process' is not considered a process which follows a distinct sequence of procedures, makes evident that the term is somewhat contradicting actual practice. Thus, it points out that it is important to have full awareness of the main activities and the sequence of such activities in a research project.

In order to allow the reader to get an understanding of the key elements of this research and how it was organized in respect to the four objectives and research questions, the following figure 2.1 is presented. It is of importance to mention how such a model should be considered a simplified illustration of the actual research process. In fact, the researchers felt the process as a messy, back-and-forth between activities and outcomes, which is in line with the observations of Gill and Johnson (2010).

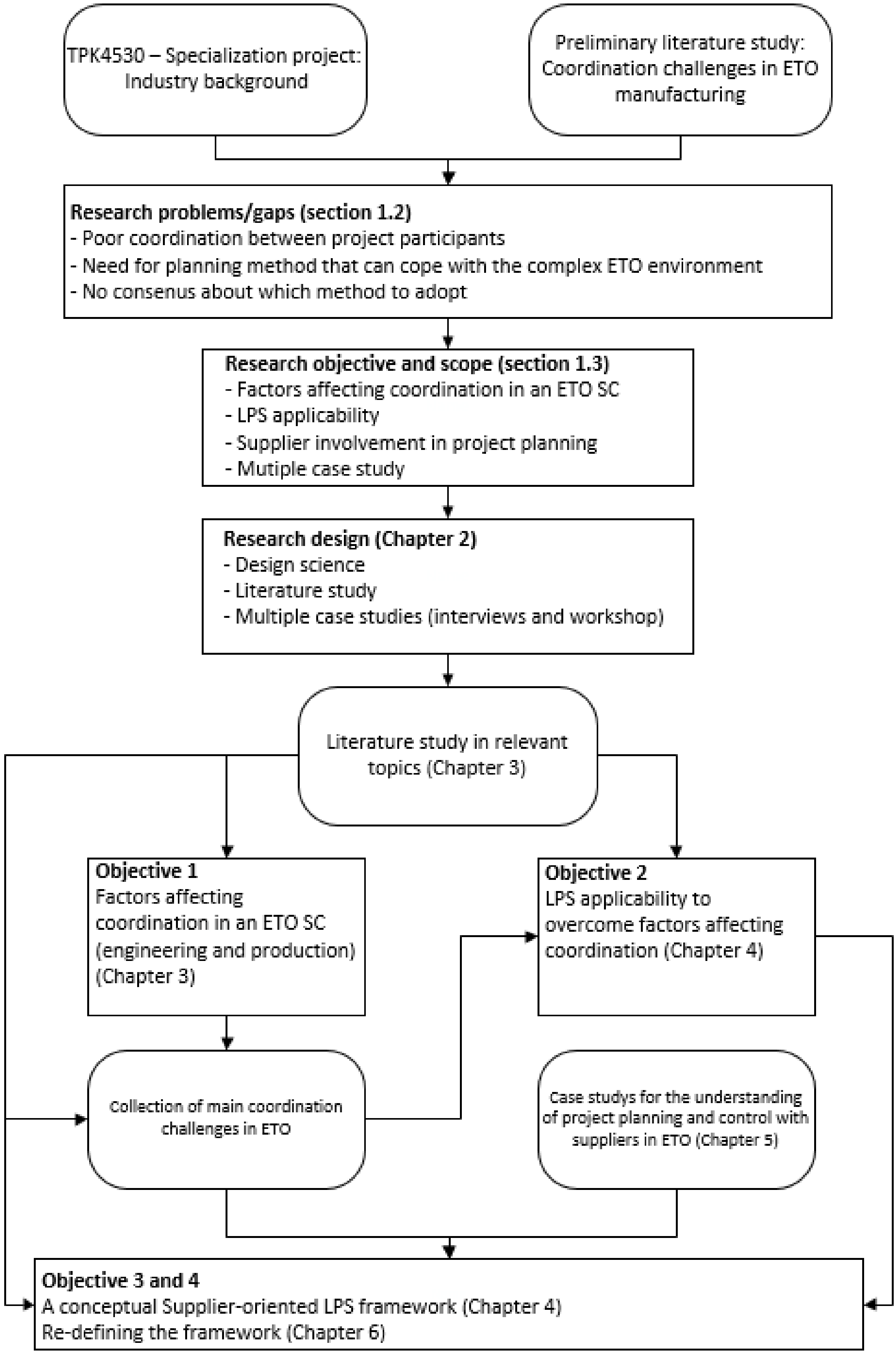


Figure 2.1: The main master thesis activities (rounded rectangles) and main results (rectangles). The arrows signify 'provided input for'

Literature Study

In order to explore the factors affecting coordination and consequently project planning in the ETO sector, a literature study was conducted during the early phases of this research. As ETO companies' ability to effectively coordinate cross-business activities is essential to avoid delays, cost overruns and quality problems, the literature study therefore aimed at developing a better understanding of the overall ETO sector with an emphasis given to coordination between engineering and production as well as supplier involvement in project planning. Since SI is considered a 'vague' term, a broad and informative study was important to fully grasp the concept and relate it to the ETO sector. An investigation of how other authors have approached the research phenomenon has made the researchers completely familiar with theory. Problem description and research questions have set the focus area in the literature study. It was decided to separate the literature study into the following parts as shown in table 2.1.

Literature study categories	
Project manufacturing	Definitions Project planning
ETO	Characteristics ETO SC SCM SCM in ETO
Coordination	Mechanisms Coordination in ETO
Lean Construction	Last Planner System Criticism
SI	Concepts SI in ETO Coordination effects

Table 2.1: Literature study categories

The main databases used for conducting scientific journals were: Google Scholar, Science Direct, Emerald, and NTNU BIBSYS / Oria. No specific preferences were given regarding choice of literature, however, the researchers decided to only investigate journals of a certain quality in terms of their acknowledgement in academia. After conducting the literature, the most relevant papers were grouped thematically in a shared excel file, then closer analyzed. In the start up, the amount of papers were expanded with the help of the initial ones, also refereed to as the snowballing technique (Ang, 2014). This method is known to be a convenient approach when the scope is uncertain, which it was in the start up of the project. The most relevant papers were given a specific Latex code and included in the theoretical study.

Multiple Case Study

As a research method, the case study approach is used in many situations to contribute to our knowledge about contemporary issues of practical relevance, where the researcher has no control over the phenomenon (Yin, 2009). A single or a small number of cases set in a real-world context can provide an in-depth understanding and can be a good tool for answering 'how' and 'why' questions. The outcome can help developing new theories and ideas used for theory testing and refinement (Voss et al., 2002).

A case study can either be single or multiple. The researcher decides prior to the data collection which method to use, in order to address the research questions (Yin, 2009). Even though multiple case studies are known for being more robust than a single case study, both approaches are variants within the same methodological framework (Yin, 2009). A single case study is known as a self-contained experience with a unique context (Ellram, 1996). Consequently, the single case study approach will be applicable when it represent a critical case to test well-formulated theory. A multiple case study approach is used for predicting similar results among replication, which will result in a richer theoretical framework. Ellram (1996) argues that the researcher has to evaluate the number of cases needed to achieve the desired generalizability of the results.

The LIFT research program as a project will be implemented in a multidisciplinary consortium of companies. However, it was decided to reduce the number of company participants due to the limited time scope of this master thesis. The multiple case study in this thesis contains two companies, A and B. The names of the companies are left out due to a confidential agreement.

Semi-structured interviews

During this master thesis three semi-structured interviews and a workshop have been conducted. Interviews are used to collect information and opinions from interview participants on a particular subject (Flick, 2009). These interviews are either used for conducting exploratory, explanatory or evaluation research (Matthews and Ross, 2010). For this master thesis, both exploratory and evaluation types of research motivated the semi-structured interviews.

The interviews were conducted in order to get a better overview of the main challenges in regards to planning and control. The aim was to understand the project planning process and how the companies involve suppliers throughout a project (exploratory) and compare it to the literature study findings (evaluation). However, for this master thesis, some data collected during the previous semester (TPK4530 production management specialization project) will be used. This is mainly the internal planning environment at case company A (section 5.1.2), from interview 1 (section 8.2.1).

The master students formed the interview questions with an overall aim of mapping the internal planning process. The questions were distributed to case company A a few hours prior the interview. PhD candidate Gabriele H. Jünge was leading the discussion followed by researcher Mikhail Shlopak and Espen Rød. Both are employed at Møreforsking Molde and active project participants of the LIFT research project. From the case company the following people participated at the interview: Head of project department and project manager, head of fabrication/procurement and head of quality department. To the extent possible, the interview participants were asked the same questions in order to increase reliability of the collected data.

Interview 2 and 3 were separately conducted (March 2016) with each of the two case companies A and B. The aim was to investigate how both companies include their suppliers throughout a project in regards to project planning (section 8.2.2). To the extent possible, the interview participants from both companies were asked the same questions in order to increase reliability of the collected data. The overall planning environment in case company B was also mapped during interview 3. PhD candidate Gabriele H. Jünge was present as an observer in both interviews. The data collected by the master students and Gabriele H. Junge was after both interviews evaluated and discussed. It was perceived that such discussion would increase the reliability of the answers as individuals might have different perceptions of the same situation. Participants from company A during interview 2 were head of fabrication/procurement and head of quality department, while the project manager from company B was present during interview 3.

In collaboration with member of the LIFT research program, the master students assisted and organized a workshop in March 2016 on project planning and control in ETO industry. The participants were project managers, project-, technical- and production coordinators, planners, discipline coordinators, engineers, and others in the ETO project organization. The master students helped to develop assignments which opened for discussion in regards to how to involve suppliers in the planning and control throughout a project as well as how to assess their performance (section 8.3). Such a workshop might have several limitations due to the fact that participants work in groups and might influence each other. However, the workshop contributed to an increased understanding of how professionals in the industry perceive the challenging and complicated process of involving suppliers in project planning. This helped the students to structure the future work and objectives for this master thesis.

3 | Theoretical background

Theory provides an explanation of observed behavior and prediction of future behavior (Koskela, 2000). It is by far the basis of generating tools for analysis, designing and controlling. It provides common language through which cooperation of individuals engaged in projects is facilitated and enabled. From a practical and concise point of view, theory is the ultimate benchmark for improving performance (Koskela, 1999).

3.1 Project manufacturing

Definition of project

There are several definitions of projects in literature. Table 3.1 shows some of these definitions. A common notion is how projects can be seen as a temporary endeavour. Temporary in this context refers to the way that the purpose is to accomplish a set of objectives and then terminate. Harrison (1992) further points out the scope and complexity in projects as well as the need for inter-organizational interactions.

Sources	Definitions
Project2000 (1998)	An effort that has character of being a one-time undertaking, with given objectives and limited scope of work, that is executed within time and cost limits
PMI (1996)	A project is a temporary endeavour undertaken to create a unique product or service. Temporary means that every project has a definite beginning and a definite end. Unique means that the product or service is different in some distinguishing way from all similar products and services
Harrison (1992)	The project is a discrete undertaking, that is, it has a start and a finish. It has finite objectives, often including time, cost and performance goals. The project is of significant size, value, and complexity, and is under time pressure for completion. The project involves the integration across organisational boundaries of groups, departments, organisational units and companies.

Table 3.1: Project definitions (adapted from Asbjørnslett (2003))

Projects in this thesis are related to a temporary endeavour undertaken to create a unique product (an ETO company in our case, ref. chapter 3.2). Hence, the objective includes physical output. However, in the main literature used in this thesis, different terminology has been used in order to describe the same operational concepts (Adler, 1995; McGovern et al., 1999; Ballard, 2000). The concepts are related to the terms production and manufacturing which have been used interchangeably in literature. One concept refers to the physical process of transforming raw materials or supplies into a finished product, whereas the other concept refers to the overall environment which facilitates a physical output. The following section outlines the main differences between the two terms based on the American Production and Inventory Control Society (APICS) definition.

Production vs. Manufacturing

The two expressions *'to produce'* and *'to manufacture'* are in many cases considered as synonyms to one each other. Consequently, the phrases have become interchanged words as one might consider using both to describe a process in which something new is made. Although this is true, it is not completely accurate as there are a few important differences between the two terms.

As the term *production* is commonly used both within and outside an industry, *manufacturing*, as opposed to this, is often limited to the industrial sector. Production is according to APICS (2013) defined as: *the conversion of inputs into finished goods.* Hence, any transformation which results in an output that creates utility is production. However, there are numerous ways of describing production in practice as the input does not necessarily mean physical material. An example could be non-material goods such as ideas, information and services.

According to APICS (2013) *manufacturing* is define as: *A series of interrelated activities and operations involving the design, material selection, planning, production, quality assurance, management, and marketing of discrete consumer and durable goods.* As it becomes clear that manufacturing is a broader category that includes production, it can be argued that all manufacturing includes production. However, not all production includes manufacturing.

In order to properly distinguish both concepts based on the definitions provided, manufacturing can therefore be seen as an all encompassing term which production falls under. Hence, the total output is in this thesis described with the term manufacturing, while production is only a part of a process which results in that total output.

Based on the definition of project, production and manufacturing, projects with a physical output will be within the scope of this thesis, defined as a project manufacturing approach were production refers only to a sub task. Projects are more than just physical production and need to be referred to as an approach which includes a set of interrelated tasks to be executed.

3.1.1 Project planning

The knowledge on how to manage unique projects is covered by project management literature. Such management method is composed of three main functions: planning, organizing and controlling. These are the basic principles project managers rely on in order to fulfill the objectives related to time and monetary results. Consequently, project planning has gathered great attention as a key decisive factor in the achievement of project's goals. However, challenges arise early at the initial planning stages in regards to identify which activities need to be carried out in order to complete the project on time (Andersen, 1996). According to Dvir et al. (2003, p. 90) *"The issue becomes even more severe when the kind of activities that should be undertaken depends on the outcome of earlier activities"*. However, there is a clear overall agreement between researchers on how a minimum level of planning is required in any project (Dvir et al., 2003) because of four basic reasons (Kerzner, 2013a):

- Eliminate or reduce uncertainty
- Improve the efficiency of the project SC
- Better understanding of the objectives
- Systematic monitoring and controlling of work

Indeed, project planning is an essential part of project management and is according to PMI (2008) an important factor when it comes to managing and controlling projects. This assumption is based on the fact that planning reduces uncertainty and increases the likelihood of project success (PMI, 2008). Moreover, Kjersem and Emblemsvåg (2014) argue how planning is executed can contribute to both success and failure of meeting the project's objectives. However, as most problems hardly ever have a single root cause, the reason for poor planning is not always easy to quantify (Emblemsvåg, 2014b). Kwak and Anbari (2009) argue that justifying the field of project management as a distinguishable academic principle is naturally more difficult as its more interdisciplinary than other management disciplines. Different factors such as defined project goal, effective communication, commitment from senior management and project planning and monitoring has been recognized to contribute to project success during the execution phase (Pinto and Slevin, 1988). Moreover, Laufer and Tucker (1987) recognized that improvements regarding planning are the first an foremost factor beneficial for success. However, decades later, planning related problems were still identified as root causes of project failure:

"Poor overall planning, no systematization of planning process, lack of re-planning on a regular basis, plans based on insufficient data, and planning performed by a single planing group" (Kerzner, 2013b, p. 55). Oehmen (2012, p. 6) also identified ten challenges themes in managing engineering programs, in which two of them are directly connected to project planning and control: *Insufficient planning* and *improper metrics.* Moreover, a research carried out by the United States Accountability Office showed that from 413 failed projects, 79 % of the root causes were related to poor planning (Kjersem and Emblemsvåg, 2014). Assaf and Al-Hejji (2006) had the same conclusion when another survey on time performance was conducted for different types of construction projects in Saudi Arabia.

Although planning as a tool is an important and well documented criteria in project management literature, frequent project failures as well as lack of commitment towards project management methods (Forsberg et al., 1996), have made researchers investigate the underlying theory of project management to see if there is a need for a renewal. Koskela and Howell (2002b) argue that there is no consensus about which methods to adopt since the underlying theoretical basis of project management is not satisfactory.

According to Wiendahl et al. (2005), planning can only be effective if the process of setting goals and establishing the procedures of attaining them are intertwined with the process of controlling activity execution. Hence, the key in any planning and control system is to plan, initiate and control product delivery in order to match company output and logistic performance to the customer demand. In other words, such system should monitor production and in the case of unforeseen deviations readjust the order progress or the production plans Wiendahl et al. (2005). However, the effort in regards to gather reliable data and the dissemination of information has received limited attention (Laufer and Tucker, 1987). This showcases how planning might simply become a process of preparing plans with the application of different techniques and consequently not the managerial process which it should be. This is very much the case for projects within the ETO industry. Consequently, there is still a great need for planning methods that can assist the chaotic project environment (Little et al., 2000).

3.2 The ETO sector

The following chapter aims to describe the ETO sector, its main characteristics and challenges regarding SCM and coordination, which consequently affect project planning. The main emphasis is given to coordination between the different ETO SC entities, within the scope of engineering and production collaboration.

3.2.1 ETO characteristics

ETO is a project-based manufacturing approach ranging from highly integrated companies with in-house manufacturing to pure design and contract organization (McGovern et al., 1999). Common for these companies is how they are characterized by low volumes of a high variety of products in a non-repetitive environment where value is created based on customer requirements (McGovern et al., 1999; Wortmann et al., 1997). These requirements are usually translated into complex products, which cause a high degree of customer and supplier involvement through the phases: design, procurement, manufacturing, installation and commissioning (Braiden et al., 1993). Long lead times, low customer satisfaction and poor resource planning are usually a result of these interactions, as all of them frequently affect planning and control functionalities (Hicks et al., 2000). Bertrand and Muntslag (1993) stress how the ETO environment is full of uncertainty as it might be that not all information is available when decisions are made throughout the project. However, the project still needs to continue its natural course, increasing the complexity of the project planning situation. Many decisions at the beginning of the project such as setting the lead time, capacity and price are established under the circumstances of limited information, consequently turning into a major challenge to prevent delivery time from becoming unacceptable long, or in other words, not as promised (Stavrulaki and Davis, 2010). The previous statements bring to light how project management capabilities are critical and essential for these firms (Winch, 2013).

3.2.2 The ETO SC

Information and material flow

Bertrand and Muntslag (1993) argue that ETO SC have two main flows: physical (material flow) and nonphysical (information flow). While former concerns the overall SC with production, assembly, installation and commissioning activities, the latter involves the product development through the stages of planning, design, engineering and procurement (Bertrand and Muntslag, 1993). Between the ETO company and its customers and supplier there are two stages of interactions (McGovern et al., 1999). The first stage is related to the preliminary development of the conceptual design and only includes non-physical activities. At this point the company is part of a tendering phase in response to an invitation to tender for a particular design. Major components and systems are defined followed by obtaining information on cost and lead times. The latter involves contacting selected suppliers. The desire is to match overall project costs and lead time, which often requires a number of phases of negotiation. A detailed technical understanding of customer requirements is essential in order to achieve success at this stage, as well as meeting price, delivery and quality requirements. After the contract has been awarded is when the second stage takes place in regards to customer involvement. These non-physical activities include the development of an overall project plan and detailed design. This is followed by the overall physical SC activities. The level of vertical integration determines whether these physical activities are performed by the company itself or by third parties (Hicks et al., 2001). As the project evolves so does the interdependency between information and material flow. Consequently, changes at later stages have higher impact on production efficiency (Simchi-Levi et al., 2008). Shin and Robinson (2002) argue that managing such flows requires a system approach to identify, analyze and coordinate the interactions, which can help in understanding the relationships between various activities across companies.

Outsourcing

Outsourcing refers to the transfer of work to outside suppliers rather than completing it internally. In order to increase cost efficiency, outsourcing to low cost countries has become an increasing trend for ETO companies operating in high-cost countries (Hicks et al., 2000). Hence, product development usually involves multiple worldwide companies in an ETO SC (McGovern et al., 1999; Hicks et al., 2000). Moreover, Schönsleben (2004, p. 12) argues that *"For products of a certain complexity, it is not a single organizational unit that will handle design and manufacturing. Instead, the tasks are distributed among several companies or among different organizational units within a company"*. This is referred to as a network organization, which Morris and Pinto (2004) defined as an alliance of several organizations for the purpose of creating products and services for the customer. Design and engineering activities are typically core capabilities for the focal company, while production activities are usually the ones outsourced (Hicks et al., 2000). In the latter situation the engineering company might still control the corresponded SC network (Stavrulaki and Davis, 2010). While outsourcing might increase flexibility related to configuration possibilities, it might also at the same time narrow the flexibility to deal with design changes as well as the scope of concurrent engineering (CE) (Hicks et al., 2000). The CE philosophy *"promotes the incorporation of downstream concerns into the upstream phases of a development process."* (Yassine et al., 1999, p. 165). Such overlapping of sequential activities is a common method used to reduce the project lead-time. Kjersem and Emblemsvåg (2014, p. 681) mention some of the advantages and disadvantages for such network organized organizations, summarized in table 3.2.

Network Organized Organizations	
Advantages	1) Cost reduction 2) High level of expertize by hiring firms with know-how (the company can focus on developing its core competencies) 3) Flexibility by being able to combine own resources with talents of companies
Disadvantages	1) Coordination breakdowns due to challenges in adjusting mutual objectives or accepting close collaboration 2) Loss of control due to the fact that the focal company does not have direct authority over the hired team 3) Conflicts due to different perspectives on value, priorities and culture

Table 3.2: Advantages and disadvantages of network organized organizations (based on Kjersem and Emblemsvåg (2014, p. 681))

3.2.3 SCM

The fact that individual companies nowadays tend to compete as SC and not as individual entities (Lambert et al., 1998), has according to Harrison et al. (2005) made companies exercise SCM (Tommelein et al., 2008). Consequently, there has been a strong awakening of the attention in academia. Moreover, as the majority of the expenses in numerous organizations lie outside their lawful limits, the greatest opportunities for improvement are found in a more extensive SC (Christopher, 2005). Hence, SCM has an overall goal of adding value throughout the whole value chain, including the customer (Lambert and Cooper, 2000), and ultimately increase competitive advantage (Mentzer et al., 2001). In order to successfully implement SCM and achieve the latter, it is argued that all entities within a SC must overcome their own stand-alone function and adapt a process approach. In other words, strategies should not be formulated in parallel with other business functions. Hence, all processes within a SC should be perceived as key processes in order to fulfill customer requirements (Lambert et al., 1998). There has been an exponential growth of interest from researchers since the early 1990s (Burgess et al., 2006). Consequently, as the theoretical body of SCM continued to evolve, various definitions emerged. One of the more recognized definitions from Mentzer et al. (2001, p. 18) follows:

> *"SCM is defined as the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the SC, for the purposes of improving the long-term performance of the individual companies and the SC as a whole."*

SCM as a set of activities

In order to demonstrate consistency with the established philosophy, management practices need to show support (Mentzer et al., 2001). A number of activities have been suggested in literature in order to achieve this. Mentzer et al. (2001) summarized these activities as shown in table 3.3:

	Activities
1.	Integrated behavior
2.	Mutually sharing information
3.	Mutually sharing risks and rewards
4.	Cooperation
5.	The same goal and the same focus on serving customers
6.	Integration of processes
7.	Partners to build and maintain long-term relationships

Table 3.3: SCM activities (adapted from Mentzer et al. (2001))

The work of Bowersox and Closs (1996) relates to the set of activities from Mentzer et al. (2001) and concluded that SCM is a set of activities with an overall goal of coordinating the different SC entities. Moreover, Cooper et al. (1997) and Lambert et al. (1998) argue how *mutually sharing information* between these entities, especially in regards to planning and monitoring, as well as *mutually sharing risk and rewards*, are prerequisites for implementing a SCM philosophy. The latter activity is seen as especially important for the long-term focus and cooperation between SC entities. *Cooperation* refers to how companies should work together in order to achieve common goals, which consequently is affected by whether the SC entities have *the same goal and the same focus on serving customers* (La Londe et al., 1994). Cooper et al. (1997) and Lambert et al. (1998) argue further how the implementation of SCM needs the *integration of processes*, where cross-functional teams are highlighted as a way of achieving integration. Moreover, as SCM is based up on a series of relationships, it require partners to build and maintain *long-term relationships* (Cooper et al., 1997; Lambert et al., 1998) with a time horizon extending beyond the life of the contract.

As a number of entities in a SC contribute in the value creation, stresses the importance on how these entities should work together (Arshinder and Deshmukh, 2008), thus, the previously described SCM activities have been suggested in order to achieve an unified system. In other words, SC entities need to coordinate with each other. Coordination is considered as a fundamental elements in SCM (Ballou et al., 2000), whereas SCM is considered the driver for such coordination (CSCMP, 2010). This is also in line with the SCM definition from Mentzer et al. (2001) which further argues how a lack of inter-firm coordination will prohibit SCM for achieving its goals. Mentzer et al. (2001) argue on what is referred to as antecedents, as a prerequisite for a successful SCM, and how it is essential that each entity within a SC has the right antecedents. Mello (2015, p. 14) summarized and described these antecedents as shown in table 3.4:

Antecedents	Description
Trust	It is a major determinant of commitment and is essential to make cooperation work and to overcome mutual difficulties such as power, conflict and lower profitability.
Commitment	It is an essential ingredient for the successful long-term relationships. Both trust and commitment lead directly to collaborative behaviors.
Interdependence	It is a motivation to negotiate functional transfer, share key information and participate in joint operational planning.
Organizational compatibility	It is defined as complementary goals and objectives as well as similarity in operating philosophies and corporate cultures. It has a strong positive impact on the effectiveness of the relationship.
Vision	The creation and communication of a market-winning competitive SCM vision shared by the whole SC provides specific goals and strategies to accomplish the opportunities in the marketplace.
Key processes	The focus of every process is on meeting the customer's requirements and that the firm is organized around these processes.
Leader	Leadership capable of stimulating cooperative behavior between participating companies. It plays a role in coordinating and overseeing the whole SC.
Top management support	It has a critical role in shaping an organization's values, orientation and direction and has substantial impact on organizational performance. The lack of top management support is a barrier to SCM.

Table 3.4: SCM antecedents

SCM in ETO

In spite of the attention SCM has acquired among different industries and research, the extrapolation of the concepts and methods towards the ETO sector has faced challenges related to the characteristics of such sector (Formoso and Isatto, 2008). Consequently, limited research has been done (Burgess et al., 2006) compared to the high-volume sector, such as the automotive industry (Nishiguchi, 2004; Bresnen, 1996; Burgess et al., 2006). The primary shortcoming of SCM in the low-volume sector is according to Hicks et al. (2000) how it has been centered around mass production of standardized products in repetitive and routine assembly processes. Close operational integration between buyers and suppliers is a typical requirement for these receptive processes as they are normally controlled using just-in-time (JIT) systems[1] in a well and long established SC. In these types of SC, research has been focused on the focal company and how it has been able to attain a significant degree of control over its much smaller suppliers (Bresnen, 1996). However, ETO SC have different structures, meaning that in order for an ETO organization to deliver the goods or services, it relies on a combination of preexisting and custom-made SC (Tommelein et al., 2008). In addition, SCM in a project based setting can be characterised by having immature and temporary SC structures, meaning that they must be rapidly established, configured and must remain flexible in order to handle the demand variability that can arise throughout the project execution. Hence, SCM in projects can be understood as the coordination of independent but related SC to the project while also designing, executing and improving the project's SC. Furthermore, it is unlikely that the same SC will be used (e.g new supplier) from one project to another, even if the product or service might almost be the same (Tommelein et al., 2008). Therefore, a long lasting buyer-supplier relationship is not necessarily achievable in the low-volume sector SC (McGovern et al., 1999). McGovern et al. (1999) argue further how demand uncertainty narrows the possibility for establishing cooperative long-term relationships between a buyer and supplier in the ETO sector. In fact, as some items may be acquired on infrequent basis and in low volumes, the power may shift towards the supplier, which is in complete contrast with many companies in the high-volume sector. Moreover, Hicks et al. (2000, p. 186) found the buyer-supplier relationship to differ significantly due to: *different levels of vertical integration; variations in volume for different types of components; the degree of customization of components; the levels of CE activity; the value of the item concerned; the proximity to the critical path; and the power balance within the particular buyer/supplier relationship.* It is due to this variability that Hicks et al. (2000) question the transferability of SCM practices from the high-volume to the low-volume sector.

As a huge part of the total contract value (items and services) is usually handled by other entities than the focal company (Dubois and Gadde, 2008), the importance of a

[1] JIT is an inventory strategy companies employ to increase efficiency and decrease waste by receiving goods only as they are needed in the production process, thereby reducing inventory costs.

more collaborative approach towards suppliers has become recognised as important in the low-volume sector as well. However, research has shown how 'win-lose' transactions and mutual mistrust are both characteristics and consequently an outcome of multisourcing activities (Puto et al., 1985; McGovern et al., 1999; Hicks et al., 2000). As core capabilities are typically related to the non-physical processes (section 3.2.2), has resulted in a higher focus towards product capability and features, rather than design for manufacturing (DFM). In fact, Eppinger et al. (1994) argue how it is essential for ETO companies to involve production in early stages of a project in order to better manage design and reduce costs. This is in agreement with with Burt and Doyle (1993) who argue how 75-80% of total avoidable cost is controllable at the design stage. However, such involvement stresses the need for coordination between cross-business activities (Thompson, 1967; Adler, 1995; Terwiesch et al., 2001; Petersen et al., 2005).

3.3 Coordination

The overall intention behind coordination is to align plans and objectives of individual participants to improve the overall SC performance and consequently achieve a common goal (Blau and Scott, 1962; Shin and Robinson, 2002). Shin and Robinson (2002) argue that all decisions within a SC need to be aligned in order to be fully coordinated. Taxen (2003) argues that coordination is closely related to communication and shared meaning. Overall, coordination is seen as an information processing activity. Nevertheless, previous research in academia has shown that the ability for groups and individuals to act together in a coordinated manner is affected by diverse barriers, such as: *poor communication*, *inadequate cooperation*, *conflicting goal priorities* and *inadequate leadership* (Sherman, 2004, p. 271). Such coordination problems are according to Thompson (1967) reliant on the organization's structure and goal. In fact, after studying several organizations, Thompson (1967) argues that the need for mutual adjustment between different sectors becomes even more important when these organization are considered complex. Complex in the sense that various interdependencies exist (Thompson, 1967).

Thompson (1967) was not the only one trying to provide the basis for an understanding of coordination. In fact, other researchers such as Ven et al. (1976) were also early out contributing to organizational theory in regards to the knowledge of the phenomenon. The idea is that the coordination effort should not be minimized by isolating interdependent functions as complexity increases and how different types of coordination mechanisms are needed in order to manage these interdependencies. In other words, the need for interactions and thus higher coordination effort will increase the higher these interdependencies are (Thompson, 1967; Ven et al., 1976). However, Kazanjian et al. (2000) argue that when interdependent activities are performed by different entities, the coordination becomes especially challenging. In addition, Galbraith (1973) also contends that in order to maintain the consistency of the decisions made, a higher degree of coordination effort is acquired for handling the diversity and uncertainty of interdependent activities.

The extent to which the output of one activity influences another is how Thompson (1967) defines interdependence. In his study, three types of interdependence were identified: *pooled*, *sequential*, and *reciprocal*. *Team arrangement* was suggest by Ven et al. (1976) as a fourth interdependence when he based his work on the previous study done by Thompson (1967). The dependency between activities increases from pooled to team arrangement and consequently also the challenge of coordinating them. However, as dependency increases it does not exclude the previous types of interdependence (Thompson, 1967). In other words, all companies have pooled interdependence while the most complex companies have all four types of interdependence. A description of each interdependence based on Thompson (1967) and Ven et al. (1976) adapted from Mello (2015) is shown in table 3.5:

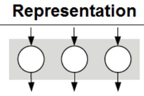
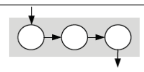
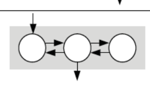
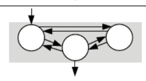
Interdependence	Representation	Description
Pooled (independent)		Action in each activity can proceed without regard to action in other activities.
Sequential		Each activity has to be readjusted if any of them fail to meet the expectations.
Reciprocal		For the actions in one activity, the other activities have to be adjusted.
Team arrangement		The activities are adjusted jointly and simultaneously at the same point in time.

Table 3.5: Typology of interdependence based on Thompson (1967); Ven et al. (1976)

The typology of interdependence made both Thompson (1967) and Ven et al. (1976) identify four types of coordination mechanisms: *standards*, *plans*, *mutual adjustment* and *team arrangement*, shown in table 3.6. Such coordination mechanisms contribute to formalization, which is defined as the variety of mechanisms that contribute to a structured and clear innovative management approach (Vandevelde and Dierdonck, 2003). The establishment of routines and rules that make sure consistent actions are made through several units is what characterize *standards*, while setting predefined goals by which actions from each unit are governed characterize *plans*. Communicating between several units drives *mutual adjustment* while *team arrangement* showcases how interdependent teams work together in order to develop and implement solutions.

Interdependence	Form of coordination	Applicability
Pooled (independent)	Standardization	Stable, repetitive and low variety environments.
Sequential	Plan	Requires less stability and enables some degree of change.
Reciprocal	Mutual adjustment	More variable and unpredictable environments.
Team arrangement	Teams	Unpredictable environments under changes and uncertainty.

Table 3.6: Relationship between interdependence and coordination (Thompson, 1967)

3.3.1 Coordination mechanisms

Previously described literature has shown how an adaption of mechanisms that support interactions and information exchange between actors is needed (Thompson, 1967; Ven et al., 1976; Adler, 1995). Generally, any mechanism which contributes to improve company barriers can contribute to improve coordination (Mello et al., 2015). As Adler (1995) investigated a number of development projects, a taxonomy of project coordination mechanisms was identified in order to improve coordination between engineering and production under uncertainty. It distinguishes both Thompson (1967) and Ven et al. (1976) modes of interdepartmental interactions (ref. table 3.6) in each of three temporal phases: *pre-project*, *product and process design* and *production. Pre-project coordination* refers to the coordination during initial stages of a project. *Product and process design coordination* characterize the phase required for product and process definition while *production coordination* is after the 'release' to production operations. The outcome is a matrix containing twelve cells each representing a specific coordination mechanism. According to Adler (1995), the most efficient interdepartmental coordination mechanism is that which is able to deal with the uncertainty of this specific product/process. Such a mechanism would ensure an acceptable fit between product design and the production process, which is the overall objective of coordinating such departments (Adler, 1995). Table 3.7 shows the typology of the different design/production coordination mechanisms (Adler, 1995).

	Pre-Project Phase	**Design Phase**	**Production Phase**
Noncoordination	Anarchy	Over-the wall	Work-arounds
Standards	Compatible standards	Design rules or tacit fit knowledge	Production flexibility
Schedules and Plans	Capabilities development schedules	Sign-offs	Exceptions resolution plans
Mutual Adjustments	Coordination committees	Producibility design reviews	Producibility Engineering Changes
Teams	Joint development	Joint teams	Transition teams

Table 3.7: A typology of Design / production Coordination Mechanisms (Adler, 1995)

The coordination effort increases from top to bottom (Thompson, 1967) in the matrix. Product / process fit uncertainty is conceptualized in the two dimensions of fit novelty and fit analyzability and both are taken into account regrading the choice of specific mechanisms. *A great degree of fit novelty creates uncertainty by making the choice of product design parameters more sensitive to the choice of process parameters or vice versa* (Adler, 1995, p. 157). In other words, the number of exceptions with respect to the organization's experience of the product / process fit problems, defines the project's fit novelty. The case study of Adler (1995) suggests that the newness of product and process technology will increase the fit novelty. In that case, the organization should intensify the information transfer between design and manufacturing departments as greater fit novelty calls for more intensive use of the available product / process fit information. Novelty is therefore solved earlier in a project adapting more interactive mechanisms (Adler, 1995). The second dimension of fit uncertainty is analyzability which Adler (1995, p. 158) defines as *the difficulty of the search for an acceptable solution to a given fit problem*. In other words, as novelty defines the number of fit issues, analyzability defines whether these are easy or difficult to resolve. When a product requires a new manufacturing process, when the entire product can not be fully grasped by the design tool or when such tool do not allow a simulation of product performance is when Adler (1995) argue that there is a low analyzability. Lower degree of analyzability of the product / process fit problem will consequently create uncertainty from the very beginning of a project. As analyzability depends on generating more information (i.e. drawings, specifications), it needs to be, according to Adler (1995), addressed in the later phases of a project. Low analyzability therefore demands a greater share of later phases in the overall coordination effort. Nevertheless, Adler (1995) argues how coordination tasks as well as mechanisms might change over the course of the project. The following list (Mello, 2015, p. 36) gives a short description of the coordination mechanism in each phase of the matrix. Adler (1995) provides a more comprehensive description of each mechanism.

- *Compatibility standards* - Standards used to maintain a certain degree of consistency within the organization.
- *Capabilities development schedule* - A task force sets up a schedule to develop capabilities, but has no authority over the execution.
- *Coordination committees* - Forum that meets regularly to enable mutual coordination of activities.
- *Joint development* - Teams develop together and implement solutions.
- *Design rules or tacit knowledge* - Rules based on learning from previous projects or designer's tacit knowledge of manufacturing.
- *Sign-offs* - Manufacturing signal that it accepts or refuses the responsibility for

making a product.

- *Producibility design reviews* - Review conducted with the aim of ensuring that producibility considerations were respected.
- *Joint teams* - Bring manufacturing engineers into the design process to advise designers.
- *Production flexibility* - Use of flexible machines that produce a variety of items in an efficient way.
- *Exceptions resolution plan* - Plan for the resolution of exceptions (producibility issues not solved during design).
- *Engineering changes* - Coordinates the implementation of changes proposed by marketing or required by customers.
- *Transition teams* - Design engineers move to manufacturing on temporary assignments in order to perform design revisions.

Throughout the years, other researches have also addressed coordination in different organizational contexts acknowledging sharing preliminary information (Terwiesch et al., 2001), co-location of key individuals (Pinto et al., 1993), job rotation and mobility (Ettlie, 1995), interdisciplinary training (Postrel, 2002) and cross-functional teams (Griffin and Hauser, 1992). Griffin and Hauser (1996) argues how written polices, job descriptions, rules and standard procedures could enable integrated pattern of behaviour and consequently coordination as they provide the entities with a general framework. According to Song and Parry (1993), this might reduce conflicts and help to achieve project goals. Such activities and roles, however, need to be well defined, planned and scheduled (Moenaert and Souder, 1990). Other researchers have both addressed informal and formal mechanisms and how there is a higher need for the latter as the project progresses (Song et al., 1997). The use of such mechanisms will also be affected by the level of project complexity in terms of uncertainty. A flexible organizational structure is suggested for such companies, which implies formal mechanisms such as cross-function teams (Griffin and Hauser, 1992). Cross-functional teams are according to Griffin and Hauser (1996) probably the most helpful mechanisms to overcome the organizational barriers. Moreover, formalization also validates product development (Souder and Chakrabarti, 1978). Hence, uncertain environments strong-case the need for formalization in order to cope with barriers affecting coordination. This is in line with both Kerzner (1998) and (Jones et al., 1997), who argue how coordination in projects is achieved through horizontal organizing governed through networks of relationships rather than by lines of authority.

3.3.2 Coordination of the ETO SC

As literature has shown (section 3.2), the ETO sector is characterised with a combination of both uncertainty and numerous of interdependencies between the different entities, especially due to the disintegration of engineering and production. Such characteristics pinpoint the high level of complexity in such sector, which consequently increase the coordination effort required in order to successfully manage an ETO SC. In fact, previous literature has shown how the ability to coordinate internal and external processes arise as a challenging necessity for competitive advantage in an ETO SC (Konijnendijk, 1994; Hicks et al., 2001). Consequently, improving performance in an ETO SC is very much related to the ability to improve engineering and production activities in regards to coordination (Thompson, 1967; Ettlie, 1995; Adler, 1995; Terwiesch et al., 2001; Petersen et al., 2005; Mello, 2015) (illustrated in fig. 3.1). According to Thompson (1967), such coordination is handled by employing multiple forms of coordination mechanisms. However, the discussion about which specific mechanism to choose is very much open in literature (Mello et al., 2015). Nevertheless, specific coordination mechanisms that are capable of handling situations with limited standardization and hardly any repeat orders is needed to successfully coordinate an ETO SC (Konijnendijk, 1994).

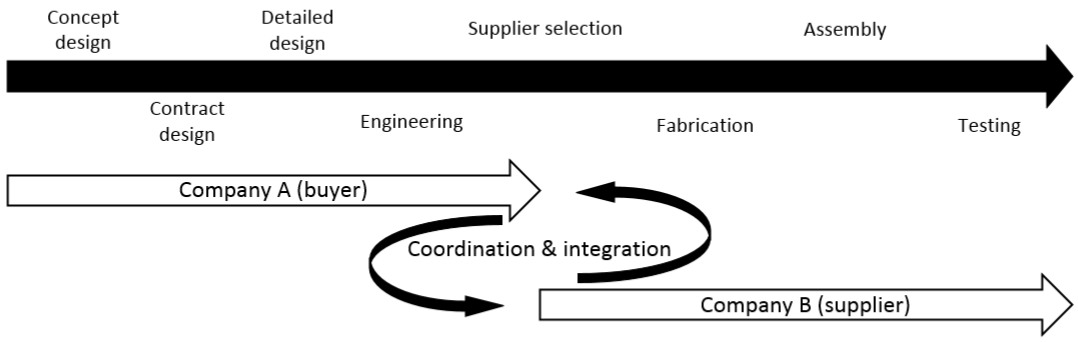


Figure 3.1: An example of an ETO network involving two companies (based on Mello and Strandhagen (2010))

A dynamic and decentralized environment is according to Thompson (1967) reliant on flexibility and adaptability. Thompson (1967) suggests project management as an evolving form of organization in order to handle such complexity at the company interface. Performance in an ETO SC is highly dependent on the people interacting with technology and executing processes. The most difficult part of successfully managing coordination involves managing these people. Hence, Arshinder and Deshmukh (2008) argue that in order to achieve coordination, more studies are required to explore qualitative issues related to human-based systems. However, as several factors might affect the effectiveness of such coordination between entities in an ETO SC (i.e. customer-specific products, massive interdependence between activities, increasing level of outsourcing and complexity and change), has made researchers argue that in order to address effective solutions regarding coordination, such factors need to be better understood (McGovern et al., 1999; Hicks et al., 2001; Pandit and Zhu, 2007).

Factors affecting coordination in an ETO SC

Hicks et al. (2000) argue that there are three major phases that require coordination in ETO: tendering (sales/marketing), product development (engineering) and product realization (production). The latter activity has according to several researchers been disintegrated without considering the correspondent coordination needs (Ettlie, 1995; Ulrich and Ellison, 2005). In fact, when several companies are involved, Hui et al. (2008) argue that the complexity of coordination becomes especially challenging when the focal company has low dominance over the activities performed. Moreover, due to the fact that frequent customer changes are so common in ETO manufacturing, coordination between activities is even more challenging (Reddi and Moon, 2011). A deep understanding of the project dynamics is therefore vital for the project managers to understand, in order to effectively manage product changes (Love et al., 2002). The performance of a SC is according to Reddi and Moon (2011) influenced by the capability of a single supplier to coordinate such changes. Hence, changes have a great impact on lead time and need to be coordinated across multiple entities. However, poor coordination among project participants in the ETO SC has shown to generate delays, which consequently increase lead time (Pandit and Zhu, 2007). Therefore, improving delivery performance in an ETO context depends on both reducing lead times and increasing the reliability of lead time estimates (Hicks et al., 2001). According to Bogus et al. (2005), a higher degree of concurrency is needed to reduce project lead time. However, as concurrency increases between engineering and production, so does the uncertainty and inderdepencencies (Klein et al., 2003) which will acquire even more coordination (Terwiesch and Loch, 1998). Such overlapping of activities is dependent on good communication between the entities (Holmes and Yazdani, 1999; Maier et al., 2008) and thus the management of the information transfer (Bogus et al., 2005). As shared design information might be incomplete, creates according to Terwiesch et al. (2002) an additional source of uncertainty when engineering and production is overlapped. Such uncertainty makes the management of ETO manufacturing especially challenging (Hicks et al., 2001) and might generate conflicts due to different perceptions of the same situation as well as dissimilarity in shared information (Kazanjian et al., 2000). An outcome might lead to an misunderstanding between engineering and production, which might resolve in an 'we versus them' attitude, consequently affecting project performance (Vandevelde and Dierdonck, 2003) and in worst case increase the possibility of project failure (Souder, 1981). Such functional differences might be even more severe when the setting is a SC due to differences in e.g. culture and language (Mello, 2015). Overall, concurrency between engineering and production when changes are not predictable or under control might lead to severe challenges regarding communication, integration and rework (Mello et al., 2015). On the other hand, when design is advanced enough to eliminate the uncertainty of using preliminary information, is when Terwiesch et al. (2002) argue concurrency as appropriate. Hence, starting production (downstream) before engineering activities are finalised (upstream), becomes less risky the faster the evolution of the latter activity is (Bogus et al., 2005).

Previous literature (section 3.3.1) has shown how the downstream coordination effort is affected by the maturity of the design (Adler, 1995). As customer changes usually result in engineering changes (upstream), the maturity of design/technology usually generate production changes (downstream) as well (Mello et al., 2015). According to Adler (1995), innovative design generates uncertainty which might delay the decision making in the process of development and result in errors which are only discovered during production. This strongcases the need for an understanding of the physical product development process during design (Eppinger et al., 1994; Hicks et al., 2001) as well as the importance of downstream capability to solve problems in an ETO SC (Brown and Bessant, 2003). Table 3.8 summarizes the main factors and challenges affecting the effectiveness of coordination and consequently collaboration between entities in an ETO SC. Although there might be others, the presented factors reflects the main challenges highlighted in the present master thesis literature study.

Factors	Description	Challenges	Related references
Geographic dispersion	High level of outsourcing	- Loss of control	1, 13, 2
		- Conflicts due to different perspectives on value, priorities, and culture (coord. breakdown)	1, 24
		- Narrow the flexibility to deal with design changes as well as the scope of CE	25
		- 'Win-lose' transactions and mutual mistrust between entities	14, 15, 25
		- Need for mutual adjustments between plans and objectives	19, 1
High level of uncertainty	High level of uncertainty in product and process design during the early engineering and design phases (low level of specification)	- Frequent changes need to be coordinated between different interdependent entities	3, 16, 20, 30, 22, 23
		- Incomplete information	4, 17, 18, 26, 21
Overlapping engineering and production (CE)	Activities performed simultaneously (CE)	- Incomplete information causes an even higher level of uncertainty	12, 13
		- Increase in interdpendencies	11, 26, 29, 13
		- Especially challening with engineering changes	24, 26
		- High interdpendence in critical path	27
		- Requires good communication between task members	10, 11, 25, 26, 28
Production capability	Capability to deal with changes downstream	- Dependent on staff skills, knowledge and experience	9, 25
		- Supplier capality (quality, performance and consistent delivery)	3, 8
Maturity of the design technology	The level of knowledge available to minimize risk	- Need to understand physical product development during design	4, 5, 6, 7, 8, 25

1: Kjersem and Emblemsvåg (2014)
2: Hui et al. (2008)
3: Reddi and Moon (2011)
4: Adler (1995)
5: Brown and Bessant (2003)
9: Arshinder and Deshmukh (2008)
10: Holmes and Yazdani (1999)
11: Bogus et al. (2005)
12: Terwiesch et al. (2002)
13: Kazanjian et al. (2000)
6: Eppinger et al. (1994)
7: Hicks et al. (2001)
8: Mello et al. (2015)
14: Puto et al. (1985)
15: McGovern et al. (1999)
16: Little et al. (2000)
17: Bertrand and Muntslag (1993)
18: Stavrulaki and Davis (2010)
19: Thompsen (1967)
20: Simchi-Levi et al. (2008)
21: Vandevelde and Dierdonck (2003)
22: Hao et al. (2008)
23: Love et al. (2002)
24: Mello (2015)
25: Hicks et al. (2000)
26: Terwiesch and Loch (1998)
27: Hartley et al. (1997)
28: Maier et al. (2008)
29: Mark et al. (2003)
30: Braiden et al. (1993)

Table 3.8: Factors affecting coordination in an ETO SC

The following sections aims at investigating whether coping with the challenges as an outcome of the factors, can be inspired by philosophies derived from the Lean Construction Institute (LCI), which has recognised the need for improvements regarding planning and control in order to facilitate coordination between such interdependent activities in a project based environment (Ballard, 2000).

3.4 How can LEAN inspire ETO project planning?

The breakthrough of the low-volume, high customized production introduced a paradigmatic change in research, extensively dominated by mass production (Hicks et al., 2000). As previously described, such research has uncovered different types of challenges related to the need for ETO organizations to take the role of global value chain coordinators (Gosling et al., 2013; Junge et al., 2015; Mello, 2015) Nevertheless, there has been limited efforts on how to solve these challenges. On one side Gosling et al. (2015) and Hicks et al. (2000) have stressed the importance for the adaptation of SCM into the ETO sector, while Emblemsvåg (2014b), Koskela (1992) and Ballard (2000) have suggested and successfully implemented suitable lean principles regarding project planning and control in shipbuilding and construction. In fact, construction has over the past 40 years struggled with poor performance (Aziz and Hafez, 2013) due to poor planning (Kerzner, 2013b), which has led the way for lean-based tools to emerge. A significant number of research (Kim and Ballard, 2000; Ballard, 2000; Aziz and Hafez, 2013; Kalsaas et al., 2014) has shown how lean inspired tools have revolutionized the construction industry by improving project planning and control throughout the project from design to delivery, which consequently have improved coordination in such industry. In fact, the construction industry shares similarities with other ETO organized projects. Such similarities might be enough to permit the adaptation of tools, approaches and methods from one industry to another. Four peculiarities have been identified which separate the construction industry from mass production (Nam and Tatum, 1988; Warszawski, 1990) and are further described in regards to their relevance to the ETO sector within the scope of our thesis.

1. One-of-a-kind nature of projects
2. Site production
3. Temporary multiorganization
4. Regulatory intervention

1. *One-of-a-kind nature of projects:* This is in line with most ETO definitions arguing how demand orders usually acquire completely new or different degree of adaptation of an existing design that demands one-off production.

2. *Site production:* To some extent, as many ETO companies have in-house manufacturing. However, due to the trend of outsourcing, product development usually involves multiple worldwide companies in an ETO SC. In other words, production could be scatted around the globe and not in one specific site (section 3.2.2).

3. *Temporary multiorganization:* Very much so as subcontracting is used to a large extent in ETO manufacturing. Literature has shown how different barriers are affecting the ability to establish long-term relationships, such as demand uncertainty (section 3.2.3). Moreover, complex requirements often need to be first understood in order to pick the appropriate supplier. Hence, different requirements for the same type of product might demand different suppliers. Location is also one of the main reasons why companies tend to often change suppliers from project to project.

4. *Regulatory intervention:* As codes might change in construction, this is very much the case for many companies in the ETO sector as well. Products are often delivered to industries with a very strict safety regime on the edge of technology (Emblemsvåg, 2014a). An example could be a huge vessel for the oil and gas industry or equipment manufactures for the very same vessel.

Koskela (1992) argues how the outcome of these peculiarities is what makes the construction industry complex and uncertain. As literature has shown, the overall characteristics of the ETO sector share to some degree the same peculiarities and consequently many of the same challenges as the construction industry. The most important challenges as an outcome of the peculiarities might be how the project-specific products, which have a fluctuating demand cycle, are all affected by uncertain production conditions and everyday deviations from the plans (Hicks et al., 2000; Dainty et al., 2001). Moreover, the need for different temporary multiorganizations strong case how these independent groups need to collaborate, many of whom have never met before and will never meet again, which makes coordination, communication and commitment crucial. The outcome gives a good initial argument for looking into literature regarding managing projects under the lean construction umbrella.

3.4.1 Lean Project Management

The aim of applying lean philosophy in ETO manufacturing is inspired by the key competitive factor in the high variety-low volume market, which is achieving reliable lead time estimates (Hicks et al., 2000). An effective way of achieving such reliability is by avoiding delays, which is considered as waste since costs are incurred and delivered value is diminished (Powell et al., 2014). The Lean Project Management philosophy from LCI, understood the high uncertainty which ETO organizations experience and how insufficient planning and control would lead to imminent and diverse types of delays (section 3.1.1). At the same time, the complex scenario was an opportunity to pursue the lean ideal which in a conceptual sense is looking for improving the management of the the uncertainty and variations, an unfulfilled issue by specific project management techniques (Kjersem and Emblemsvåg, 2014). However, it is legitimate to argue that the lean principles which originated from the Toyota Production System (TPS) may be inflexible and consequently not applicable to markets like the one ETO organizations are submerged into. Nevertheless, the research of Powell et al. (2014) emphasises how an adaptation of the lean principles is needed to fit the context in which the lean ideal is to be pursued. Koskela (1992) refined the lean principles to the construction industry, leading to the conceptualization of the Lean Project Delivery System (LPDS).

Lean Project Delivery System

LPDS is the most developed and researched system within LCI, which has as an objective to develop knowledge regarding project based manufacturing management covering design, engineering and construction (Lean Construction Institute, n.d.).

LPDS is the materialization of lean project management philosophy which has its roots in studying the effects of the interdependencies (harmonization between main contractors and subcontractors) and variation along the SC of a project (increasing reliability) (Koskela, 1992). The novel project management philosophy seeks to overcome the deficiencies Koskela (1999) identified as idealizations in the traditional project management literature. The main deficiencies centered in not recognizing other phenomena in the project development other than transformation (input and output) and not recognizing transformation as only a part of the value of the output rather than the whole. An outcome of acquiring the transformation views is the sub-optimization of processes leading to buffers, which increase costs but most importantly inflexibility to respond to changing markets (Winch, 2006). According to the research of Koskela (1999), the stand-alone predominant transformation concept can be seen as the originator of complex, uncertain and non-optimal flows, while exponentially expanding non-adding value activities. Therefore, Koskela (1992) introduced the concept of a project as a flow of materials and information. In this scenario, the transformation process is enriched and complemented by the flow and value generation analysis. The idea behind the flow view is to create a continuous flow through the different stages of a project, as it creates benefits in terms of time, value and costs rather than focusing on the efficiencies of each individual sub-process in each stage. The key is to reduce variability in the execution of the processes rather than increase efficiency. Flow emanates from eliminating waste through the processes by applying principles such as lead time reduction, variability reduction and simplification (Tommelein et al., 2008). The overall intention is to generate predictable hand-offs between different production units (Kalsaas et al., 2014). The value generation view attempts to reach the best possible value from the customer's point of view by capturing and fulfilling all the requirements. Balancing the three main pillars (transformation, flow, value) of LPDS might be a better approach regarding SCM to adapt and fit to the ETO environment with a better management of the material and information flow in such sector.

LPDS is defined as a structured, controlled and improved system in pursuit of the transformation, flow and value goals previously described (Koskela et al., 2002). The LPDS model divides a project in three phases: lean design, lean supply and lean assembly (illustrated in fig. 3.2). Compared to the traditional project management methods from the PMBOK (PMI, 2013), this system highlights the relations between phases and participants in each phase, considering that each phase will overlap with the previous and the following phase (see figure 3.2). The valuable outcome of this process is extensive communication between entities during a project, leading to a holistic understanding (Koskela et al., 2002).

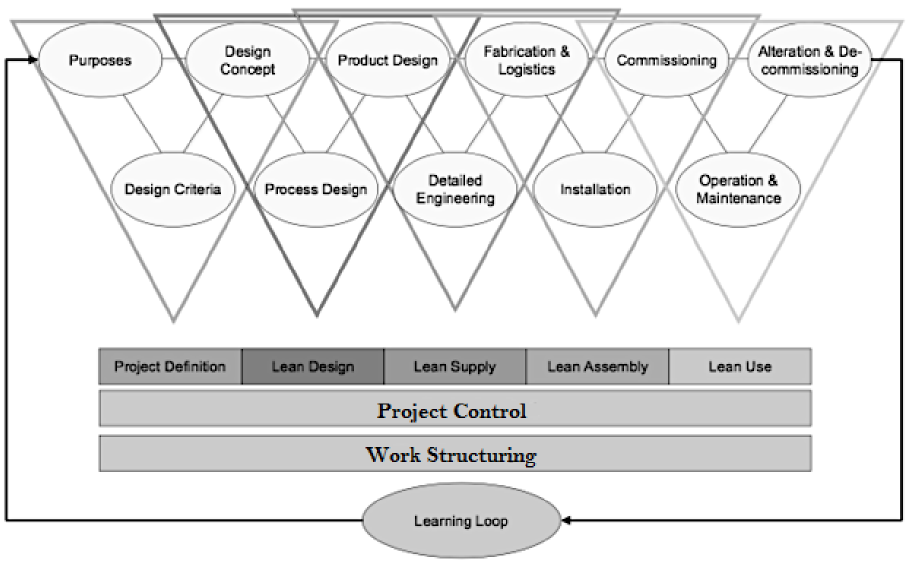


Figure 3.2: Lean Project Delivery System (Ballard and Howell, 2003a)

The design phase is related to the *project definition*, consisting of the alignment of values, concepts and criteria. Any failure in alignment will send back the project to re-definition. Traditionally, design has always been perceived as product design. However, *lean design* in LPDS integrates process and product design simultaneously by considering production and assembly process in the design process. To some extent, LPDS calls for DFM, a method that can potentially save time and cost on avoidable iteration (Boothroyd, 1994) (section 3.3.2)

In addition, Ballard (2000) included deferring decisions until the last possible moment, generating a greater time span for developing and exploring alternatives. By avoiding the immediate selection of options and design tasks, allows interdependent specialists to start the tasks within their limits without worrying for possible conflicts with other decisions from related specialists (Ballard and Howell, 2003a). The *lean supply* phase consists of detailed engineering, fabrication and delivery. These stages have product and process design as prerequisites, which enable the different project entities to know what to fabricate in detail and when to deliver those components. *lean assembly* phase starts off with the delivery of material and relevant information for assembly and ends when the final product is released to the customer (Ballard and Howell, 2003a).

Project management crosscuts throughout the project supporting the different phases in LPDS. It consists of two main parts (See figure 3.2): Project planning, which in LPDS is referred to as *work structuring*, where project's process design takes place while design, engineering and assembly efforts are aligned with the SC capabilities (Tommelein et al., 2008). The overall target for structuring the work is the creation of reliable work flow while delivering value to the customer. The other key element is the *project control* which shapes the assignments ready to be performed, consequently fostering commitment. It helps to make the necessary adjustment to steer the project towards how it can best meet the project's objectives.

The concept of LPDS as a lean project management approach was taken forward by Ballard (2000) into the development of a practical project planning and control method called *Last Planner System (LPS).*

The Last Planner System

The project planning and control method or system, as its creators Glenn Ballard and Greg Howell denoted it, has been perceived as a main driver for the palpable application of lean project management (Hamzeh et al., 2009). LPS as any system incubated by the lean philosophy, seeks perpetually for the elimination/reduction of waste, deviating from the conventional project management approach. In essence, the planning and control system were designed to shift the focus of control from workers towards the physical and non-physical flows that link the production units. LPS empowers control by forcing problems to be visible at the planning stage. This assists in developing foresight, while increasing reliability by smoothing variations and reducing uncertainty, enabling optimization (Ballard, 2000). Whether it is considered as a planning and control system or method, LPS is a new way of thinking that actively uses the relevant theory of the new lean foundation of project management. LPS receives its name after the people on the operational level, who decide the assignments to be done for the next day and are accountable for the completion of such assignments (Ballard, 1994). These actors are true drivers of actual work rather than further development of plans. The process executed by LPS makes sure that activities *WILL* be done (based on the premise of activities that *SHOULD* be done), by considering all type of constrains (Ballard, 2000) (illustrated in figure 3.3).

The basis from which LPS was developed makes a clear distinction between *SHOULD* and *WILL* in order to foster predictability, which adds "headlights" to the project management and not only 'rear lights' (Kalsaas et al., 2014). In simple words, optimistic planning is replaced by realistic planning, an important project success variable (Kerzner, 2013a).

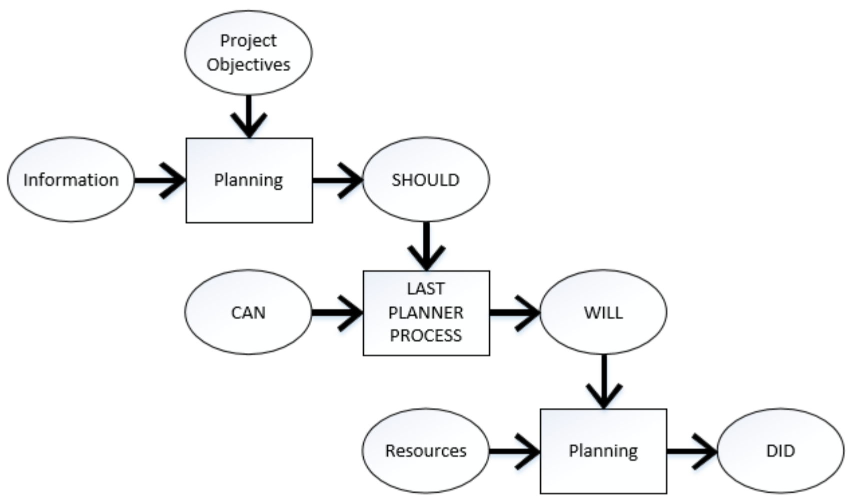


Figure 3.3: The formation of assignments in the Last Planner System (Ballard, 2000)

In order to successfully achieve the *WILL* with LPS, the creators defined five ruling principles (Ballard et al., 2009):

- Collaborative planning
- Plan in detail as tasks approach execution date
- Reveal and remove constrains collaboratively
- Make and secure reliable promises
- Learn from what went wrong

The ruling principles from LPS share common roots with SCM set of activities (see table 3.3), which both aim to converge into practical efforts for coordinating the SC. While SCM establishes the overall concept to coordinate and set prerequisites for coordination, LPS attempts to establish project planning as an optimal way to enforce coordination in the ETO environment. Nevertheless, both sides complement each other. For instance, the bullwhip effect in ETO is the representation of an important fluctuation due to constant changes, mainly from the customer. A lack of coordination causes elongation of lead time because of the excessive time buffers each entity of the SC establishes. Chopra and Meindl (2013) suggest collaborative planning as an effective measure towards the bullwhip effect which requires mainly mutual sharing of information and cooperation. The latter showcases how both, LPS principles and SCM set of activities are required to coordinate the SC. The other four ruling principles from LPS show the application of lean philosophy accentuating the waste elimination and continuous improvement which also support the coordination effort.

The more LPS started to be applied in different projects, modifications were needed to better suit the particular practical necessities of specific ETO industries. For example, Kalsaas et al. (2014) included the involvement across subcontractors and keeping simplicity within planning for a construction company operating in Norway. The concluding remarks from this research were that LPS can and should be tailored in order to be integrated in other project management systems, as long as its ruling principles are satisfied.

Last planner structure

The backbone of the LPS consists of two main components (Ballard, 2000):

- Production unit control

  Commitment / Weekly Work Planning (WWP)

- Work flow control

  Look-ahead planning

  Phase scheduling

  Master scheduling

Inside each component, different levels of planning processes are found. These processes shape the main framework for LPS.

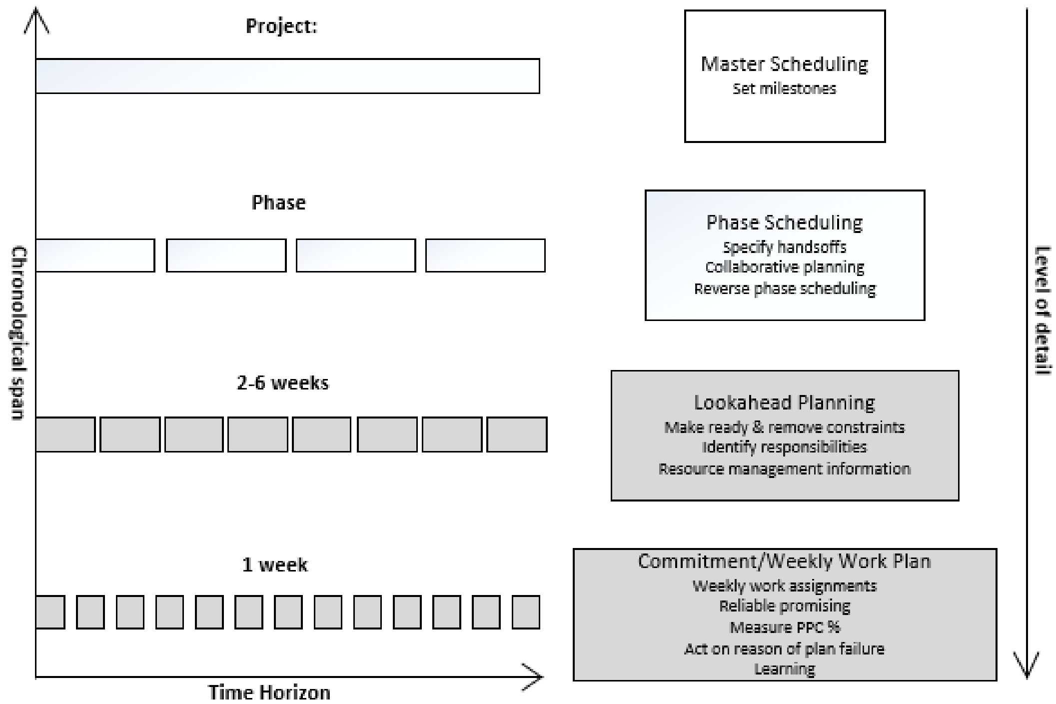


Figure 3.4: Planning stages/levels in the Last Planner System for project planning and control (Hamzeh et al., 2009)

Weekly Work Planning

The *weekly work planning (WWP)*, also known as commitment planning, represents the most detailed plan in the system. The interdependence between the tasks of various specialist organizations is made crystal clear. During this stage, last planners drives the production process where site managers and crews together decide the tasks for the present week during short meetings called 'lean meetings'. The production unit is shielded from upstream uncertainty by only making quality assignments with reliable promises (Ballard, 2000). In other words, to go further in execution, assignments are previously sorted in the right sequence, with extremely clear instructions and all prerequisites in place.

Koskela (2000) defined seven prerequisites that must be satisfied in order to consider an assignment executable:

1. Information on design
2. Component and materials
3. Workers
4. Equipment
5. Space
6. Connecting or previous work
7. External conditions (e.g. government regulations)

The workload must also be adequate, based on the capacity of the unit producing such tasks. This phase of LPS resembles the theory of execution of the new foundation of project management since the WWP is based on the idea of language/action perspective where commitment and two ways of communication are considered as key ingredients during execution.

At the end of each period, statuses of assignments are reviewed for measuring the reliability of the planning. The key performance index (KPI) in this component resumes the number of planned activities completed divided by the total number of planned activities. This index is known as *Percent Plan Complete (PPC)*.

$$PPC\ (\%) = \frac{number\ of\ completed\ tasks}{number\ of\ assigned\ tasks}\ \times\ 100 \tag{3.1}$$

For incomplete tasks, continuous improvement is applied by conducting an analysis in order to discover the reasons for non-completed tasks. Finding the right countermeasures as well as corrective actions are then carried out (Ballard, 2000). The ingredient of learning to control used in LPS suits the scientific experimentation model, an aspect also considered in the control theory of the new project management foundation.

Look-ahead Planning

The second main component of LPS manages the work flow between production units and is known as the look-ahead plan.

Diverse organizations have used different methods for maintaining consistency in the project flow. The most common methods include forecasting and buffering (Hamzeh et al., 2012). Forecasts shows clear limitations as they only anticipate variations of the inputs and are always wrong. LPS has adopted buffering in the look-ahead planning as the method to mitigate process variations on the input and output sides.

Look-ahead planning is strategically positioned between overall project coordinated schedules and short term crew commitments with the objective of shaping work flow by maintaining a buffer of work ready to be performed. It consists of a schedule of potential assignments for the next three to twelve weeks. Activities at this stage are decomposed into work packages for the production units and checked against quality criteria in terms of scope, soundness, interdependence, sequence, size and learning (Ballard, 2000). In lean words, this is the plan from where tasks are pulled into WWP, rather than pushed as in traditional mechanisms. Pulling creates a balance load of work against capacity.

Look-ahead planning has the primary objective to align the plan with the situation. The 'CAN' feature of LPS takes its real value during this process, as planned activities are acknowledge as sound activities (Ballard, 2000).

Aziz and Hafez (2013) mention CE as parallel execution of several tasks by multidisciplinary teams aiming to obtain the best product in terms of functionality, quality and productivity. At first glance, this definition has no direct link to the principles of LPS. Nevertheless, Warszawski (1990) remarked that in order to make CE work properly, it is required to analyze beforehand the requirements of the tasks, incorporating constrains and tightening change control. The next section introduces phase scheduling, an important planning process including rough cut constraint analysis within LPS.

Phase Scheduling

The purpose of phase scheduling is to generate a plan, specifying the hand-offs between specialists, for completing each phase of the project that maximizes value generation by integrating and coordinating everyone involved. Phase scheduling in LPS acts as a link between work structuring and project control. This component of LPS highlights and links the transition from 'what' to 'how' of a phase in the project. Phase scheduling outperforms the work breakdown structure (WBS) in the traditional project management systems, since the work to be done by specialists in each phase is structured not by further subdivisions of product but by specification of process (Ballard and Howell, 2003b).

The phase schedules are based on goals of the master schedule and provide the basis for the look-ahead planning. The process starts by writing a description of work different teams must perform in order to release work from others or work that must be complete by others to release work to them. The next step is to develop a network of activities for completing the phases using reverse phased scheduling. Afterwards, the duration is applied to each activity and the logic is re-examined for any possibility for shortening the duration (Ballard and Howell, 2003b).

Master Schedule

The master schedule is the outcome of a broad and generic planning, displaying execution strategies for the project. In other words, the master schedule is just a resource rather than something to be right away executed as indicated in such plan (Koskela et al., 2010). It describes in general terms the chunks of work to be carried out over the entire project.

During this phase the milestones and budget are set to determine the overall project duration and cost, giving confidence to all stakeholders (Hamzeh et al., 2009).

3.4.2 LPS criticism

The introduction of LPS in the project management literature, implicitly brought critics towards its theoretical foundation and applicability. Lindhard (2013a) argues that LPS is limited regarding the concept of the critical path, while Winch (2006) includes how LPS is lacking theory of risk, uncertainty and organization. The critical path as a concept is very much related to lead-time since the critical path in any project is the longest path through the network of project activities that determines the duration of the project, being the shortest amount of time to deliver a project (Kerzner, 2013a). The absence of the critical path method and the critical chain method prevents to address the problem of slack which can help to exploit the time limits to increase the robustness of the schedules, meaning reliability. Furthermore, Winch (2006) argues that LPS relies entirely on trust-based relationships and diverse coordination mechanism, while Pinto (2013) established that critical chain in order to work also needs 'no blame' which can only be generated through trust. In an ironic tone, Winch (2006) remarks how LPS is just another classic buffer technique which includes a constraint analysis, characteristic shared with the critical chain method that not only is compatible with LPS but it would improve the risk management since LPS presents a lack of a concise conception of uncertainty and risk, where the latter is uncertainty to which a probability distribution can be assigned. Overall, the critical path concept is a leverage point to achieve the reliability and possible reduction of the project's duration (Kerzner, 2013a). Lindhard (2013b) coincides with Winch (2006) view regarding the omission of critical path concept and adds the critic about how LPS is only measuring the schedule quality, leaving behind the quality of work. In a more reporting matter criticism towards LPS, Junior et al. (1998) remark how LPS is lacking an explicit link to the master schedule. They argue that it is complicated and not straight forward to reflect the situation at each moment in terms of compliance with the master schedule, hence no compliance assessment can be performed. Furthermore, LPS does not consider the fact that the soundness of the 'buffer' after the make ready process activities can mutate by changes from different sources (Lindhard, 2013b). Moreover, Winch (2006) argues further that LPS lacks awareness in the different forms of organization in a project, which will shape the implementation of the planning and control method. In other words, it is argued that LPS is blind to differentiate the different degrees in which members of the SC will share and process information, hence different degrees of involvement in LPS is required. Thus, the next chapter aims to understand the supplier's specific role and degree of involvement required in order to improve performance in ETO projects.

3.5 SI in project planning

The concept of SI has been widely related to the process of new product development (NPD), a common feature in ETO organizations. The outcome of SI, mainly from the mass production manufacturing sector, such as the automotive industry, has shown mixed results, with a predominant positive correlation (Primo and Amundson, 2002; Dowlatshahi, 1998; Takeishi, 2001; Lakemond et al., 2006; Rouibah and Caskey, 2005). Despite the extensive use of the term *'supplier involvement'* in literature, it is regarded as a vague term since there is a lack of clarity for describing its true meaning in relation to the activities regarding product development, as well as in other stages of a project. Moreover, concepts such as *'supplier integration'*, *'supplier influence'*, and *'buyer-supplier interface'* have been used interchangeably in literature. This section is, thus, dedicated to reviewing, classifying, and synthesising some of the widely used definitions of SI in academia, in order to develop a comprehensive definition within the scope of this thesis.

3.5.1 SI definitions

Researchers started to address SI in the late 1980s, which consequently made it a 'hot topic' (Johnsen, 2009). As it is today, automotive industry has by far been the benchmark for SI. Major emphasis on strong communication, close relationship with cross functional teams and delegation has characterised the buyer-supplier interface definitions (Clark, 1989).

Additionally to the finding in the 1980s, Kamath and Liker (1994) suggested the need for different degrees of SI. At the same time research started moving toward different industries, resulting in even more definitions of SI. Concepts such as decision influence (Wasti and Liker, 1997; Swink, 1999; Vonderembse and Tracey, 1999), timing of involvement (Hartley et al., 1997) and contribution of capabilities (Dowlatshahi, 1998; Kamath and Liker, 1994; Vonderembse and Tracey, 1999) were included in several definitions during the next decade.

Throughout the 21st century, both terms collaboration and coordination were consistently found in SI definitions, complementing the concept of close relationship, initially used in the earlier definitions (Lakemond et al., 2006; Lau, 2011). Research showed that collaboration can only be achieved by developing a relationship, which increases trust and commitment from suppliers (Walter, 2003). In addition, research related to two European ETO companies made Rouibah and Caskey (2005) define SI as a collaboration process to coordinate the shared information between the SC entities, easing the implementation of CE across company borders. As the definitions started to become more complex and elaborated, Petersen et al. (2005) wanted to remind that SI could be as basic as the alignment of technical metrics and targets. Some years later, Takeishi (2001) studied nine Japanese automotive suppliers and explained the need for the focal company to coordinate in order to achieve collaboration with suppliers. Table 3.9 gives a comprehensive view of the different concepts discussed in the multiple SI definitions. The main overlapping terms highlighted in table 3.9 give a solid base for building the required definition for this study. The next section will give an overview of the terms and the relation to the ETO characteristics, discussed in section 3.2.1, in order to obtain a thorough definition.

Supplier Involvement Concepts	Clark, K. B. (1989)	Kamath & Liker (1994)	Wasti & Liker (1997)	Hartley et al. (1997)	Dowlatshahi, S. (1998)	Swink, M. (1999)	Vonderembse & Tracey (1999)	Wynstra & Pierick (2000)	Takeishi, A. (2001)	Primo et al. (2002)	Rouibah & Caskey (2005)	Wagner & Hoegl (2006)	Lakemond et al. (2006)	Hadfield & Lawson (2007)	Van Echtelt et al. (2008)	Lau, A. (2011)	Mello, M. (2015)
Strong Buyer-Supplier relationship	✓	✓		✓	✓		✓		✓	✓		✓	✓			✓	
Frequent/effective communication	✓	✓	✓	✓		✓	✓	✓		✓				✓			✓
Responsability of supplier	✓	✓		✓			✓	✓				✓		✓	✓		
Decision influence			✓			✓	✓							✓			
Coordination/Alignment									✓		✓			✓			✓
Collaboration											✓		✓			✓	✓
Tasks on behalf of customer								✓	✓						✓		
Contribution of capabilities/knowledge		✓			✓		✓	✓	✓	✓		✓		✓	✓	✓	
Product development involvement	✓	✓	✓					✓	✓	✓	✓		✓		✓	✓	✓
Timing of invovlement				✓						✓							
Integration					✓		✓					✓		✓			
Requirement for CE											✓						
Degree of participation		✓						✓						✓			

Table 3.9: Concepts in Supplier Involvement Definitions

3.5.2 Overlapping SI definition concepts

Product development involvement

As companies in the ETO sector started to outsource parts of the NPD activities to the different suppliers scattered around the globe, a more intimate structure of supplier management with a high focus on coordination was required leaving behind the arms length type of relationship (Johnsen, 2009). Product development involvement calls for different degree, modes and timing of active participation between suppliers and the focal company. This has brought interconnected concepts like those presented in table 3.9 as well as many impacts such as: achieving better product quality, lower project costs and delivering project on time (Lau, 2011; McGinnis and Vallopra, 1999; Wasti and Liker, 1997; Ragatz et al., 1997). Despite evidence of the positive impacts, research has also shown negative aspects or shortcomings in the desired positive impacts such as no practical influence on the overall technical success (Hartley et al., 1997) and elongated project delivery time (Primo and Amundson, 2002).

Strong buyer-supplier relationship

Strong buyer-supplier relationship is considered as an investment from both sides. Hence, a long lasting partnership based on reciprocity, cooperation and trust, which should yield competitive advantage (Clark, 1989; Kamath and Liker, 1994; Echtelt et al., 2008). According to Vonderembse and Tracey (1999), a strong buyer-supplier relationship emphasises that suppliers should be managed as an extension of the firms manufacturing system. Other researchers (Petersen et al., 2005; Handfield and Lawson, 2007) argue how the term integration substituted the strong relationship term, since buyer-supplier integration is a social process affected by a variety of social behaviours embedded in the relationship between the two partnered entities. Unfortunately for the dynamic low-volume ETO organizations a strong buyer-supplier relationship is difficult to achieve due to demand uncertainty, low buying power and the change of location in each project, as seen is section 3.2.3. Such factors have shown to generate a high degree of mistrust (Puto et al., 1985; McGovern et al., 1999), consequently an inhibitor for any kind of long lasting relationship.

Frequent/Effective communication

Clark (1989) argues how communication is the basic and essential coordination mechanism in any project, specially in the NPD projects. Moreover, Wynstra and Pierick (2000) remarked that coordination and communication takes time and effort from both the supplier and the focal company. Frequent communication was defined as the the recurrent exchange of information in order to understand the requirements with the purpose of identifying issues and elaborate joint solutions (Wasti and Liker, 1997). Through observations of the Japanese automobile manufacturers, frequent communication acquired the context of extensive communication while the term effective implied direct interaction with the right staff at the right time in the project (Clark, 1989; Womack et al., 1990). Kamath and Liker (1994) also reviewed the Japanese way of involving suppliers, noticing that communication needs to be clear, consistent and consequently effective in order to simplify the interaction with their suppliers and spare in resources. In addition, Kamath and Liker (1994) concluded that the more complex a system under the responsibility of the suppler is, the more intense communication with the buyer is needed. Nevertheless, Mello (2015) argued that effective exchange of information is only possible with a well established collaboration with suppliers. Moreover, intensity of communication can also vary depending on the stage of the project and type of supplier (Primo and Amundson, 2002). Overall, the frequency and effectiveness of communication must allow the transfer of the end user requirements to the buyer and from the buyer to the supplier, a key issue towards a better management of the frequent customer changes.

Contribution capabilities/knowledge

The many benefits of outsourcing manufacturing (section 3.2.2), cost reduction and flexibility are argued as one of the most important reasons why low volume ETO companies tend to outsource physical activities (Kjersem and Emblemsvåg, 2014). In order to achieve such flexibility, it is necessary to integrate and jointly exploit the supplier's capabilities into the organization's operations (Wagner and Hoegl, 2006). Dowlatshahi (1998) mentioned SI as a mean to achieve this. According to Kamath and Liker (1994), the contribution of capabilities relates to accessing the supplier's human resources, research and development, computer aided systems, manufacturing systems and facilities. By acquiring knowledge and external resources improvement on the operational performance, collective efficacy and innovation capabilities is expected. However the contribution of capabilities is affected by factors such as trust and power (Lau, 2011). From a broader point of view, Vonderembse and Tracey (1999) found that suppliers contribute with their capabilities every time they provide excellent product quality, performance, availability and consistent delivery. In some cases, suppliers are required to invest in order to increase their capabilities. However, such investments may only make sense if a long-term relationship is established from which beneficial long-term contracts could be awarded and that might have strategic value for the supplier (Kamath and Liker, 1994). Furthermore, Primo and Amundson (2002) highlighted the close relation of the supplier capabilities to influence the degree of SI in a project.

Responsibility of supplier

NPD is becoming increasingly risky, expensive and reliant on disparate knowledge bases spread across multiple firms (Handfield and Lawson, 2007, p. 44). In order to meet these challenges, many organizations are devolving design responsibility to their suppliers. Because of such responsibilities, suppliers play an important role in the decision making within a project (Handfield et al., 1999). According to Clark (1989) and Hartley et al. (1997), responsibility of the supplier determines the project scope, meaning the parts of the development effort that will be performed by the supplier. In agreement with Clark (1989), Echtelt et al. (2008) and Wagner and Hoegl (2006) conceptualized responsibility as the tasks suppliers commit to perform as part of a process or service that will benefit the buyer's project. Moreover, there are different levels and degrees in regards to supplier responsibility. Handfield and Lawson (2007) presented the level of responsibility in a supplier integration spectrum, ranging from *'white box'*, where the supplier is only responsible to replicate what the buyer hands in, *'gray box'* as more jointly based activities and *'black box'*, where suppliers activities are driven only by specifications from the customer. In addition, the more involved a supplier is in a project, the more competent the supplier must be (Echtelt et al., 2008) as his responsibilities for unique (not off-the-shelf) parts or sub-assembly will increase (Clark, 1989; Wynstra and Pierick, 2000).

3.5.3 Defining SI in ETO

SI can be seen as an important part of project management, since it is relevant for the main functions of such management method: planning, organizing and controlling the suppliers, which represent individual production units. Nevertheless, for nearly twenty-two years SI literature has left out the subsequent processes following product development. In fact, Echtelt et al. (2008) pointed out the need for understanding SI beyond NPD projects. Hence, the definition of SI in ETO manufacturing must relate to the planning activities at the different stages of the project. Furthermore, coordination has been a concept which has caught attention in few definitions of SI (ref. table 3.9) but with no link to project planning, leaving behind the main intention to improve the alignment of plans and objectives. Moreover, CE is barely mentioned in definitions regarding SI, and should be considered in the definition for this thesis, as it is the method to significantly reduce lead time and consequently one of the main crucial practices in the ETO environment (Sobek et al., 1999; Rouibah and Caskey, 2005; Rahim and Baksh, 2003). The following definition of SI is proposed for the purpose of this thesis:

"Supplier involvement is a reciprocal temporary strong buyer-supplier project planning collaboration based on the responsibility acquired by the supplier which intends to effectively coordinate the information sharing for delivering a product with excellent quality, performance and reliable delivery in a concurrent environment"

3.5.4 SI and coordination effects

SI has received considerable attention in a more strategic role around the mid-1990s for increasing SC effectiveness (Chang et al., 2006). The effects of SI implementation have generated several literature and research into the different business practices (Feng et al., 2010).

The research has revealed how SI is seen as a strategic resource for enhancing the organization's competitive edge by achieving fast project delivery, reliable project times, high quality levels, lower project cost, acquiring external resources and specialized knowledge, reduction of workload and an increased responsiveness to changes (Clark, 1989; Bonaccorsi and Lipparini, 1994; Takeishi, 2001; Primo and Amundson, 2002; Chang et al., 2006; Feng et al., 2010; Lau, 2011). Nevertheless, other research has demonstrated how SI can negatively impact the organization's competitive advantage (Zirger and Hartley, 1994; Brown and Eisenhardt, 1995). Increase of project development time and greater costs are presented when there is a lack of tasks aiming to increase the coordination effort or there is an inadequate timing regarding such tasks (Zirger and Hartley, 1994; Ittner and Larcker, 1997; Lakemond et al., 2006). Both aspects are influenced by the omission of identifying the contextual conditions around SI (Lau, 2011), for example the short term relationships a focal company posses with its critical suppliers in one-off projects. In this scenario, long term benefits are difficult to achieve as seen in section 3.2.3, disabling the opportunity for building routines, ensuring the alignment of capabilities and accumulating experience for future joint projects as Ragatz et al. (1997) and Echtelt et al. (2008) suggested.

The pressure for achieving competitive edge has made researchers and organizations propose tasks among different processes depending on the capabilities in order to generate a coordination effect (Echtelt et al., 2008). For instance, project management is considered as one of the main capabilities of the ETO organizations where SI and the focal company are tied by the project planning (Hicks et al., 2001). It is only by effectively managing the tasks related to this process when the coordination effects have a profound impact (Takeishi, 2001). The next table summarizes the different project management oriented tasks regarding SI that literature has proposed, aiming to generate the coordination effects for supporting the previously described competitive advantages.

The different tasks regarding SI fall into the responsibility of a specific SC entity for coordinating and enforcing them. In some cases tasks need to be coordinated jointly as seen in table 3.10.

Supplier Involvement Tasks	Responsible	References
Interdepartmental review of supplier's capabilities assesment and final supplier selection	Focal company	Liker et al. (1998), Vonderembse & Tracey (1999), Petersen et al. (2005), Wagner & Hoegl (2006), Handfield & Lawson (2007), Van Echtelt et al. (2008)
Determine moment of involvement (project stage)	Focal company	Hartley et al. (1997), Dowlatshahi, S. (1998), McGinnis & Vallopra (1999), Wynstra et al. (2003)
Determine extent (workload) of supplier involvement	Focal company	Kamath &Liker (1994), Hartley et al. (1997), Vonderembse & Tracey (1999), Wynstra et al. (2003), Handfield & Lawson (2007), Ali et al. (2008)
Provide an in depth review and suggestions of component specifications, manufacturability and lead time	Supplier	Adler, P.(1995), Takeishi, A. (2001), Wynstra et al. (2003), Echtelt et al. (2008)
Povide a short term plan regarding the production of the component	Supplier	Dowlatshahi, S. (1998), Kessler & Chakrabarti(1999), Ballard, G. (2000), Sahay, B. (2003), Feng et al. (2010)
Review and update production schedules against short term project plan	Supplier	Adler, P.(1995), Dowlatshahi, S. (1998), Ballard, G. (2000), Sahay, B. (2003)
Periodic review of supplier performance	Joint	Vonderembse & Tracey (1999), Wynstra et al. (2003), Petersen et al. (2005)
Guest engineers supporting different stages of the project	Joint	Adler, P.(1995), Hartley et al. (1997), Kessler & Chakrabarti(1999), Takeishi, A. (2001), Lakemond et al. (2006)

Table 3.10: SI Tasks and coordination effects

SI Tasks and Focal Company

One of the foremost strategic decisions before starting a project is the selection of the adequate supplier to be involved (Wynstra et al., 2003). According to Wagner and Hoegl (2006), two of the most important reasons for finding the *'right'* supplier is to secure the supplier's capabilities that best suit the project needs and allow the enforcement of the set of activities proposed by Mentzer et al. (2001), which increase the coordination effort for achieving a successful SCM (section 3.2.3). In fact, one of the main overlapping terms in the multiple SI definitions, as seen in the previous section, is the *contribution of capabilities/knowledge*. Therefore, collaboratively assessing the capabilities of suppliers to provide excellent quality, performance and consistent delivery can allow an organization, in this situation the focal company, to anticipate and address technical and organizational risks, thus increasing the project performance (Echtelt et al., 2008; Vonderembse and Tracey, 1999). In addition, a collaborative approach for assessing and deciding the supplier showcases how coordination is improved by the aligned decisions (Shin and Robinson, 2002)

In the research of Primo and Amundson (2002), a positive correlation between the supplier capabilities and the degree of SI in a project was found. The degree of SI in literature can be translated as the degree of responsibility, which is linked to the amount of workload to be performed by the supplier. Therefore, assessing capabilities gives a clear panorama of how much work can be assigned to a given supplier (Handfield and Lawson, 2007). As the coordination effort required increases due to the high level of interdependencies between activities, the effort of delegating workload increases in the same direction (Lakemond et al., 2006). In addition, the more responsibilities given to a supplier, the more influence this supplier will have on the overall project (Handfield et al., 1999). Overall, deciding the proper degree of SI for the project is finding the fit between the product design/engineering and the production processes which according to Adler (1995) is the objective of coordinating such activities.

Timing of SI has been accountable, in part, for benefits such as reduction in the development time of project (Clark, 1989; Wynstra and Pierick, 2000). Research has appointed timing of involvement as a dependent variable according to responsibility a supplier acquire, both aspects collaboratively decided by the different departments of the focal company, where early involvement is a frequent suggestion for critical components (Hartley et al., 1997; Wynstra and Pierick, 2000). Nevertheless, literature is limited to specifying the link between the timing of involvement relative to the planning structure and process (Dowlatshahi, 1998).

SI Tasks and Supplier

The early SI strategy has contributed to the reduction of the development time, to improve project output and to manage the supply risk (Zsidisin and Smith, 2005). In the literature review of the research from Takeishi (2001), it was found that there was no clear statement as to how suppliers should be involved. Takeishi (2001) proposed a group of tasks under the supplier's responsibility attempting to address the specific issue previously described. Among such tasks, the proposal of a best way to produce the component was highlighted as an essential activity at the planning stage, this in line with the conceptual framework of Echtelt et al. (2008), where evaluating the manufacturability and suggesting improvements for increasing the reliability of lead time are essential elements of the project management section.

In the research of Kessler and Chakrabarti (1999), centered around speeding up the pace of NPD, it was found that frequent milestones not only accelerate development but overall give a sense of coordination by setting time based objectives. Ballard (2000) introduces a sense of frequent milestones in LPS with the look-ahead schedule, a short term planning phase executed between the crews responsible to perform the tasks. Such planning phase within LPS has the aim to generates a time window for collaboratively removing constraints (section 3.4.1). Moreover, Feng et al. (2010) explained how suppliers can provide valuable information to a firm, e.g. the production plan for the component to be produced, which enhance the reliability of delivering on time. According to his research the previous statement is valid as long as an efficient information exchange platform is in place.

In his research, Sahay (2003) highlights the importance for organizations to involve suppliers in their critical processes for achieving a synchronized SC. Despite the mass customization scope of the research, the implementation of realistic plans by coordinating all supplier production schedules based on an overall milestone plan is seen as a beneficial area for improving SC collaboration. In fact, an essential task in the framework of Dowlatshahi (1998) for implementing SI comprises the review and update of the production schedules by the entities responsible for the production. Moreover, the commitment planning in LPS gives 'freedom' to the group of persons that will execute the task to collaboratively configure their weekly schedule which is synchronized with the overall milestone plan or phase scheduling (Ballard, 2000). As seen in section 3.4.1, the synchronization is based on the so-called lean meetings in LPS as the element for the linkage between the update of the production schedule and the overall project plan.

SI Tasks and Joint Coordination

The different SI planning oriented tasks enforced by the two actors in the SC have been presented in the two previous sections. However, there are some tasks in literature that require a joint execution. According to Vonderembse and Tracey (1999), high performance manufacturing firms and therefore high performance SC, communicate effectively the multidimensional criteria for supplier selection, which will be the basis for measuring the performance of suppliers through the project. Examples of such performance criteria are the delivery reliability and agreed quality targets. Petersen et al. (2005) remarked how both the focal organization and suppliers need to make an effort to improve the joint performance, regardless of the level of responsibility and the stage at which the supplier will be integrated. Part of the joint effort is based on agreeing and reviewing periodically the targets which according to Petersen et al. (2005) has shown to be a key element in the project team effectiveness. Furthermore, Wynstra et al. (2003) displayed a similar argument where evaluating supplier's development performance is an integral part of the supplier interface management in the presented framework of his research. The objective behind the periodic assessment is to keep an updated preferred supplier base, established on the experience of different projects. According to Wynstra et al. (2003), the assessment can be placed at a process level by reviewing the adherence of deadlines and at a product level by comparing the quality and cost against the original objectives.

The pressure to endure higher quality product and process fit made companies implement a strategy based on establishing what is called as *'Transition teams'* Adler (1995). In this strategy, engineers are sent temporarily to the manufacturing facilities on temporary assignments for any require design revisions, which will contribute to an increased understanding of the manufacturing process. In the research of Hartley et al. (1997) it is mentioned how the timeliness and the amount of communication is increased by suppliers assigning guest engineers at their customer's facilities.

The joint execution tasks as well as the other SI tasks reflect what Takeishi (2001, p. 419) suggested to managers to ask themselves: *what can your suppliers do for your? what can you do for your suppliers? and what can you do with your suppliers?*

4 | Theoretical findings

The following chapter highlights the potential of how coordination can be facilitated through LPS. A conceptual supplier-oriented LPS framework is proposed based on the theoretical findings in this master thesis.

4.1 LPS applicability

The applicability of LPS towards different ETO organizations needs to go beyond the similarities between construction, a type of ETO where LPS has been proven to be of great relevance as seen in section 3.4. The capability for handling the challenges corresponding to the different factors affecting coordination (ref. table 3.8) faced by the outsourcing ETO organizations will determine the extent of LPS applicability as well as the refitting needed for LPS to work and better fit to the environment outside construction.

High level of uncertainty

The high level of uncertainty is a contextual factor in the complex ETO environment, which derives from the high innovative and non repetitive nature of the products (section 3.2.1). Uncertainty is defined as the difference between the required information for doing a task and the available information in the hands of the organization (Bertrand and Muntslag, 1993). It is therefore challenging to translate what the customer is expecting since not all information is available when it is needed. In addition, Bertrand and Muntslag (1993) mention how information is predestined to mutate throughout the project. The incomplete information force the organizations to early plan and commit to a lead time that guides the negotiation of the due dates with the customer, which often cannot be changed once the contract is granted (Viana et al., 2013). The main outcome of the previous scenario is the constant changes between the different entities in the project. The fields of SCM and project management indicate how in general, collaborative planning rather than planning by a single group is a better approach in order to handle the uncertainty affecting flow and processing time, which can lead to project failure (section 3.1.1 and 3.2.3). Furthermore, Mello (2015) shows in his framework for coordinating ETO SC, how enabling joint project management by making plans collaboratively is a high impact technique for fulfilling the coordination effort required by ETO organizations. In addition, Bertrand and Muntslag (1993) established how planning with multiple groups could enable a better management of three important aspects of ETO: complexity, uncertainty and dynamics.

According to Koskela and Howell (2002a), LPS manages the uncertainty by establishing a collaborative planning approach and providing a decision structure in which people can decide collaboratively. Both schemes are part of the set of requirements for a suitable planning and control system for the ETO organizations (Viana et al., 2013). LPS establishes clear relations of the hand-offs between project participants through the phase scheduling, increasing the coordination. In addition, the real value of LPS for reacting to the uncertainty relies on differing the decisions until the last possible moment in the planning context. This means to plan through the look-ahead schedule in a very detailed way a couple of weeks before the actual task is going to be performed, allowing to include any changes that might occur and keep making the needed assumption due to high uncertainty (Ballard, 2000). Furthermore, the planning decisions in LPS are made collaboratively as downstream players are involved in upstream decisions and systematic collaborative efforts are made to reduce SC lead time based on removing constraints with all the parties involved in the project, specially those at an operational level performing the tasks (Ballard and Howell, 2003a).

The previous statements showcase how collaborative planning lets the information mature which gives a slack to the innovation and make changes easier to handle. Nevertheless there is still room for improvement in the LPS early planning phase, an essential stage in ETO project planning where commitments of delivering terms are settled.

Overlapping Engineering and Production (CE)

The outsourcing characteristic in the ETO companies brings a sense of multi-project environment, increasing the complexity of successfully performing the overlapping of tasks. In such environment, an excessive multitasking is performed by shared production units, for instance the shop-floor of certain supplier is shared with other customers with different projects. Interdependencies are intensified and risk is increased as most of the tasks under the responsibility of the supplier, which also is required to satisfy other customers, fall into the critical path. Any delays on the supplier's activities can delay the overall project (Hartley et al., 1997). LPS suggests gathering all the interested parties to develop the phase scheduling with the purpose of assessing the configuration and possibility of overlapping activities by looking at the duration and sequence of the different tasks of the whole project (Ballard and Howell, 2003b). Nevertheless, prioritization of tasks needs to be considered for guarding the high interdependencies in the critical path of the project, a concept not included in LPS way of thinking (Lindhard, 2013a). Moreover, in the research comparing LPS with critical chain, Koskela et al. (2010) acknowledges how critical chain method is an effective method for a multi-project environment which enables a resource provider to prioritise different tasks across projects and suggest to include the critical path concept in the agenda of phase scheduling and the look-ahead planning. In addition, Srinivasan et al. (2007) highlighted the potential synergistic relationship between critical chain and lean initiatives, such as LPS, which is in line with Kerzner (2013a) research and might help improve LPS ability to handle the interdependencies in the critical path of a project.

Concurrent activities increase the need for synchronization of changes, despite the awareness and agreement of all the members of the SC on which tasks to overlap. The synchronization has two implications reliant on each other, a more dynamic planning and planning as an integrated group. The common practice of frozen Gantt charts in many ETO projects has inhibited a holistic planning considering design, engineering, production and assembly. Researchers like Emblemsvåg (2014a) and Ballard and Howell (2003a) have shown how a constant project re-planning takes a more important role which will ease the production planning for the production units at the shop-floor level which will have as a consequence realistic order fulfilment plans (Viana et al., 2013). It is by communicating the realistic order fulfillment plans that synchronization improves and thus the possibility to increase the overlapping of tasks. LPS with the weekly work plans elaborated by the own production units, represented in this context as the suppliers, and the constant re-planning from the buffer of quality activities in the look-ahead plan, shield the order fulfillment by making public reliable promises (Ballard, 2000). However, communicating the order fulfillment and the reliability of the promises are dependent on the commitment of the supplier which also is constrained by its own production planning, an issue being out of LPS and the focal company's jurisdiction. Overall, the arguments presented highlight the attempt of LPS to reduce the isolation of interdependent and overlapped functions performed by different groups.

Geographic dispersion

The outsourcing circumstance which ETO organizations are engaged in has contributed to the coordination challenge as it affects effective communication, timing of information and loss of control over production. The affections have drawn the attention of SCM research as it gives insights for providing alternatives towards the coordination challenge (CSCMP, 2010). The sum of the coordination affections results in a stressed interdependence of diverse activities and the arise of required mutual adjustment of plans of objectives between the independent SC entities in the ETO project. The previous aspects are important points to consider when selecting and adapting diverse coordination mechanisms, essential elements for achieving the desired coordination. Although the mechanisms differ from each other, all of them share to different degrees a set of prerequisites defined by Mentzer et al. (2001) as antecedents. Trust and commitment are two important prerequisites which possesses a synergistic relation, together they are one of the main causes for collaborative behaviours (Mello, 2015). In the ETO context, research has exhibited how 'win-lose' transactions have ruled the collaborative approach required when outsourced activities are a big part of the contract value, such transactions present a more forced cooperation essence rather than actual collaboration (section 3.2.3).

Considering the overall outsourcing effects, researchers like Thompson (1967) early on suggested project management being the instrument for handling the coordination complexity, as it highlights the joint teams category from the coordination mechanism typology later proposed by Adler (1995). Nevertheless, little consideration has been granted to the project teams diaspora within project management branch of literature. This lack of attention has let the different communication and information sharing methods not to be formalized in the diverse project management techniques, letting the project managers choose their own style of communicating and sharing information. The freedom of style is based on a daily face to face interaction context held among the different project stakeholders. However, such interaction is limited when outsourcing is part of main project characteristics, making conflicts stemmed from different perspectives on value, priorities and culture difficult to overcome (Kjersem and Emblemsvåg, 2014). In fact, research (Clark and Fujimoto, 1991; Galbraith, 1995; Kazanjian et al., 2000) has indicated the importance of managing patterns of coordination and communication for achieving a successful coordination before looking at the role of information technology (IT) for bringing people and information together. The compulsory face to face interaction in the phase scheduling of LPS showing the hand offs between the different entities involved in the project, the commitment by making reliable promises in order to shield the weekly planning and the constant weekly update from the project teams creates a pattern for coordination and communication for increasing the flow between the different units in the project regardless of the location (Ballard, 2000). However, the reliability of commitments from the different entities in the SC is outside the control of LPS where trust, which is not achieved from implementing LPS, becomes an important element. Winch (2006) noticed the critical dependency LPS has towards trust-based relationships and two way communication, and stated that without these elements LPS would fall into another bureaucratic buffer method. In addition, LPS has been extensively used in projects where geographical dispersion is not an issue since all entities work at the same site (face to face interaction) and production units are exclusive during the project.

Production Capability

The most prominent capability a supplier can have is the coordination capacity to react to unpredicted changes (Reddi and Moon, 2011). This reasoning relates to the constant search for reducing lead time through coordination as SCM theory denotes. In fact, two of the antecedents for a successful SCM (Mentzer et al., 2001), organizational compatibility and key processes, introduce the importance of the capabilities of all the entities in the SC, specially for those that require most of the coordination effort. The capability of suppliers in the ETO SC need to go beyond delivering a component with high quality and performance when it is needed (Vonderembse and Tracey, 1999). The possibility for a quick adaptation to the temporary SC, characterized by fluctuation, is foremost a critical capability when reviewing and deciding the suppliers to be involved in a project (Wagner and Hoegl, 2006). LPS as key component in LPDS complies with the transformation, value and flow view (Ballard, 2000). LPS has a strong focus on achieving a good flow between project units, leaving behind the optimizations for increasing the efficiencies of the project units (Koskela, 1999). However, this argument showcases how LPS has a higher focus on achieving reliable flow, leaving behind the consideration of the individual capabilities of the SC entities. Despite the clear indication on what to fabricate and when to deliver in a realistic planning setting where problems are forced to be visible early in the planning stage (Ballard and Howell, 2003a), the outsourcing characteristic incites a multi-project environment where prioritization becomes an issue depriving such flow. Therefore, the master students suggest that the capability of suppliers affecting their efficiencies for serving several customers needs to be considered during the LPS planning process.

Maturity of the design and technology

The innovation required in the diverse projects managed by the ETO organizations has contributed to execute design and engineering phases with incomplete information, reducing the opportunity to analyze the product/process fit before production is executed (Adler, 1995). Concurrent processing of tasks added to the outsourcing of production increases the complexity even more for finding the fit between design and production. Nevertheless, CE has proven to be so far the most significant measure to reduce lead time (Bogus et al., 2005).

It becomes less risky as design and engineering activities evolve at a high pace (Bogus et al., 2005). LPS conception was thought to consider the compulsory concurrency in ETO projects by overlapping planning of the design stage with production. LPS integrates product and process design simultaneously considering production and assembly in the design process (Ballard and Howell, 2003a). The way of planning in LPS allows a product development involvement which besides being one of the most repeated concepts in the SI theory (ref. table. 3.9), enables diverse coordination effects, such as making the high pace evolution of the design for concurrent activities successfully happen. Achieving enough maturity of design happens with the early involvement of the entities in the SC at the different planning stages of LPS. The phase scheduling enables collaborative decision making with constraints removal resulting in an early understanding of implications from upstream flow. Hence, LPS attempts to perform a work structuring for understanding the physical product development during the design stage.

The following table summarizes the coverage that LPS offers regarding the challenges corresponding to the factors affecting coordination, as well as areas of opportunities to better cope with the challenges.

Coordination Factors	LPS Coverage	Areas of Opportunity
High Level of Uncertainity	• Collaborative planning as an approach for managing uncertainty and complexity • Collaborative decision structure gives solutions despite immature information • Innovation and frequent changes are managed by differing the decisions until the last possible moment and increasing detail as execution approaches	• LPS early planning phase (Master Schedule) must consider and enhance the initial commitments of delivering terms
Overlapping Engineering and Production (CE)	• Collaboratively assessing the alternatives of overlapping activities by looking at the duration and sequence of the different tasks of the whole project • Increase synchronization between tasks by communicating realistic order fulfillment plans • Shield the order fulfillment by making public reliable promises	• Addition of the prioritization of tasks as a variable to consider in the overlapping of activities when determining the critical path • Reliability of the promises are dependent on the commitment of the supplier which also is constrained by its own production planning
Geographic dispersion	• The compulsory initial face to face interaction, the commitment by making reliable promises and the constant weekly update from the project teams, creates a pattern for coordination and communication for increasing the flow between the different units in the project regardless of the location	• LPS is dependent on trust-based relationships and two-way communication • Configuration for projects with entities not working at the same site were production units are exclusively committed during the project
Production Capability	•Reliable flow between project units rather than increasing the individual efficiencies for eliminating dependencies from individual units	• LPS planning process should consider the capability of suppliers since serving several customers affect their efficiencies, increasing the risk to disrupt the flow
Maturity of the design and technology	• Planning process enables product development involvement • Integration of product and process design simultaneously considering production and assembly in the design process	• LPS requires specific supplier guidelines when outsourcing of production is an inherent characteristic of the project

Table 4.1: LPS Applicability

4.2 A conceptual supplier-oriented LPS framework

The different projects developed in multiple industries in the ETO sector and the literature around this type of project manufacturing have exposed the requirement of a considerable coordinating effort among the SC entities involved in the project. Specific attention towards the coordination between the engineering and production activities needs to be considered when these phases are executed by independent organizations. Numerous coordination mechanisms have been suggested (ref. table 3.7) to counteract the factors affecting coordination between such cross-business activities (ref. table 3.8). However, less focus has been dedicated to which mechanisms to choose and how such mechanisms can be implemented, adapted to the contextual conditions and utilized in practice.

The collaborative planning and control method in LPS has demonstrated coordination improvement in several ETO projects around the globe. Furthermore, the theoretical analysis conducted in the previous section *'LPS applicability'* implies a promising alleviation of the challenges related to the factors affecting coordination in ETO within the scope of this thesis. Moreover, the analysis enlightened the feature of LPS to structure the coordination mechanisms in practice. Areas of opportunities for enhancing the applicability were identified, where most of the required improvements relate to the involvement of suppliers and their inherent characteristics. The theory related to SI provides specific tasks which can increase the competitive edge due to the coordination effects these activities generate (ref. table 3.10). However, SI theory has not been clear on how suppliers should be involved throughout the whole project development. Therefore, a proposal for a supplier-oriented LPS framework for outsourcing ETO can contribute to improved coordination, as it enables project, processes and SC structure development.

The conceptual framework as shown in figure 4.1 is proposed and intends to define the SI contributions in the planning process of LPS. It is based on the LPS planning and control method from the Lean Construction Institute (LCI) and SI literature (section 3.4 and 3.5). The framework represents an approach to implement planning and learning routines with suppliers accountable for the production. Routines based on systematic planning provide a reasonable roadmap to achieve coordination lasting the project time but also long term collaboration benefits, such as an increased efficiency of supplier coordination which according to literature has been to some extent exclusively related to long-term relationships with suppliers.

The supplier-oriented framework is based on the four planning process stages of LPS. Each of the planning stages is related to the functional units of the project, design/engineering and production. The functional units represent independent entities performing the phases in a project to which they are accountable. The intersection between the planning phase and each functional unit form eight individual blocks and four joint blocks. Each building block consists of a set of specific tasks that need to be executed in each planning phase and can be adapted to the needs of the organizations. All the tasks in the presented framework have a coordination orientation in regards to the supplier responsible for production and have originated from LPS and SI literature. The tasks in the individual blocks fall into the responsibility of each corresponding functional unit. In this context, responsibility is referred to as enforcing and coordinating the tasks at each LPS stage. The joint blocks cross-cut the two functional units of the framework, meaning that the tasks within these blocks need the collaboration from both entities to be successfully executed.

The tasks are numbered based on the execution sequence within the two functional units and following the chronological development of the LPS planning phases. To avoid confusion, it was decided to start the numbered sequence of activities in every stage of the planning phases. The suggested sequence of tasks throughout the framework is in principle unidirectional but several tasks are iteratively executed. The blocks in the look-ahead and weekly work plan are cyclic during the project development as these two planning phases are defined as cyclical in the LPS method. It is important to remark that the joint activities like the periodic review of suppliers and the support from guest engineers are not necessarily sequentially executed and cyclical as it will depend on the situation and agreement between the focal company and supplier. Moreover, the full implementation of all the activities in the framework is subjected to the contextual situation of the project and the organizations involved in the project.

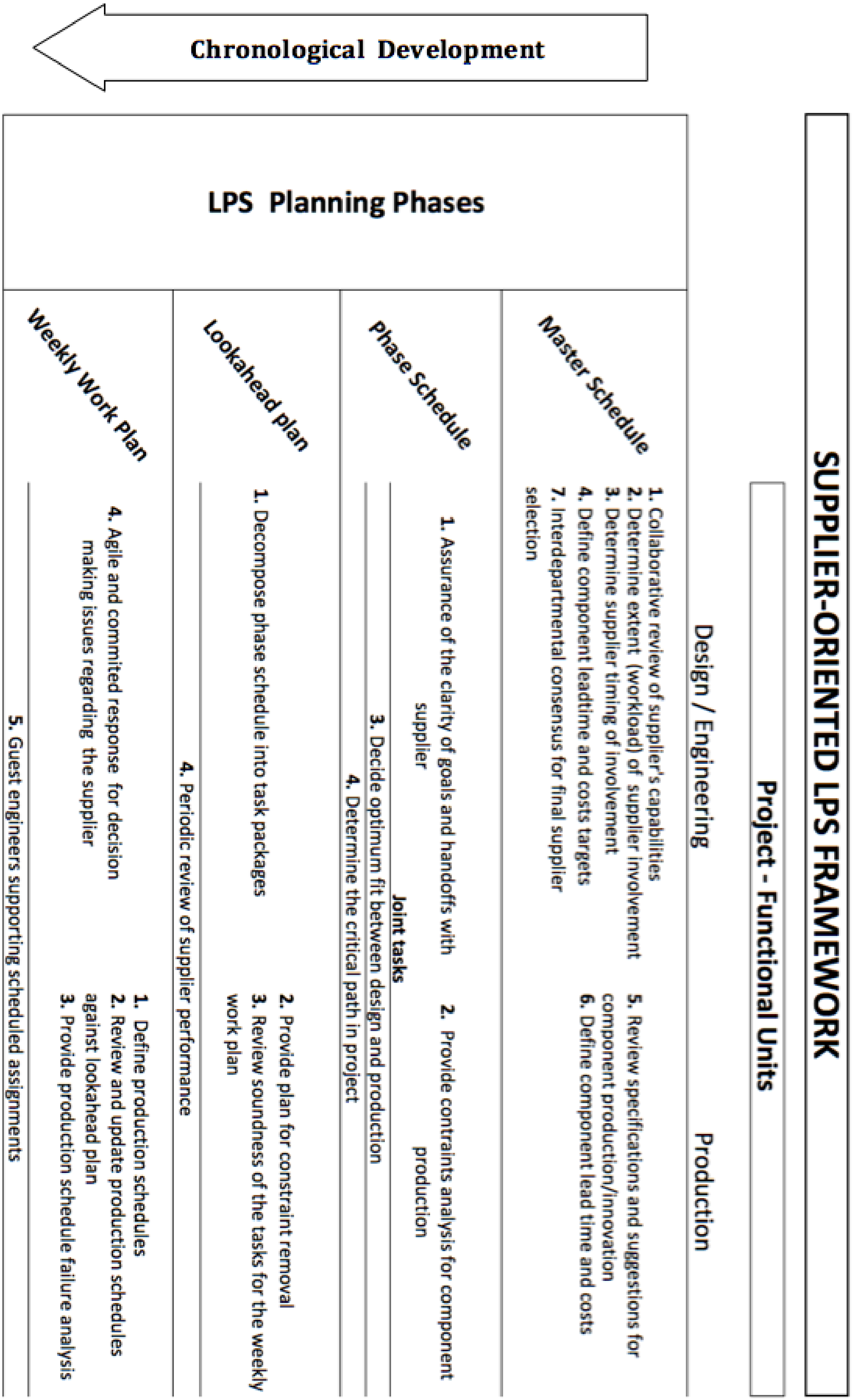


Figure 4.1: A proposed supplier-oriented LPS framework

5 | Empirical Case Study

In order to study project planning and control in an ETO SC, a multiple exploratory case study was carried out in two ETO manufacturing companies in the Norwegian maritime equipment industry. Such study helped to gain insights into the current planning and control practices during project development with a focus on the focal company and its main suppliers.

5.1 The Norwegian Ship Equipment Industry

More than 21.000 people are employed in the Norwegian ship equipment manufacturing industry. In 2014, the industry reached a turnover of almost NOK 80 billion with a wealth creation of NOK 23 billions. As of today, the industry has never had a stronger position and is consequently a significant part of the Norwegian maritime business. Sales almost trebled between 2004 and 2008 and the manufactures experienced a tremendous growth. However, after the financial crises of 2008 the industry suffered a much lower rate of growth, which resulted in a drop in turnover. In 2011 the trend turned around, and since then companies have seen an annual increase of 10 percent.

Almost 90 percent of the overall turnover in the industry comes form markets outside of Norway, which gives a good identification of how the companies are exposed to considerable international competition. However, the Norwegian based companies' ability to innovate and increase productivity has made them able to take world-leading positions.

Two-third of the Norwegian companies deliver products and services to the global offshore markets, which is equivalent to 9 percent of Norway's total export of goods and services (excluding oil and gas). Consequently, the Norwegian companies are highly dependent on the development in the international market and are thereby strongly affected by the falling demand of new offshore vessels due to historically low oil prices. Eleven out of nineteen Norwegian counties have a wealth creation of more than NOK 500 million from the ship equipment manufacturing industry, implicating the importance of the industry throughout large parts of the country (Menon Business Economics, 2015).

5.1.1 Supplier portfolio analysis

As a starting point for investigating how both companies are involving their suppliers in the process of project planning, the group decided to analyse the supplier portfolio for a typical project in the heavy-lifting maritime equipment industry. Such an analysis would give a good overview of how the companies are classifying their suppliers based on profit impact and supply risk. Before the start up of this master thesis, such analysis was already conducted by the Lift research program in collaboration with case company A[1]. The figure showcases the numerous of suppliers involved in a typical project and their position which is based on the characteristics of the product or service they provide. The exact number will differ from project to project (Project Manager Interview March 2nd (2016)), but the portfolio gives a good indication of the different amount of work that might be carried out during project development.

The outcome of the analysis showcases how only a few suppliers are considered more critical than others (e.g steal structure), due to the fact that these suppliers handle huge parts of contract value. This is in line with the observations during the workshop where participants argued how a few suppliers might affect the total outcome and should be involved throughout the whole project (Workshop March 8th, 2016). Hence, the main emphasis during the empirical study is related to the involvement of critical suppliers responsible for production.

[1]The matrix could not be included in the thesis due to right of ownership

5.1.2 Company A - Background

Case company A is a Norwegian based ETO company in the maritime industry. Its operations involves the design, manufacture and installation of highly complex and special heavy lifting equipment to the offshore industry worldwide. Each solution is highly customized and designed to meet the most challenging individual customer requirements. The case company's products, as it is the case for most other ETO products, are part of a bigger solution or final product such as offshore vessels or rigs.

In a typical project, 20 % of engineering is non customer specific, while the remaining 80 % is customer specific. On average, 20 - 22% of total costs is related to engineering, while 45-50 % is steel construction (production). All projects are handled through a project organization consisting of a project manager, project owner (the customer), project lead engineer (responsible for all technical coordination), fabrication manager (responsible for all procurement of fabrication) and other project participants from different disciplines (such as mechanical engineering, hydraulic engineering, among others).

With a growth ambition in the company's segment of the market, which is global and highly competitive, innovative and advanced lifting equipment and handling systems will not provide sufficient competitiveness in the long term. The company has to take a role of global value chain coordinator as large parts of the physical value creations are outsourced. Consequently, the company will need to be best at planning and control by following up activities for the end product to be delivered cost-effectively and in less time relative to its competitors.

Planning and control - Case company A

A project usually starts when a new contract has been granted after a tendering phase. Then the planning process starts with the sales department setting the base for a master plan by conducting budget planning and setting basic milestones, agreeing upon delivery dates followed by negotiations with the client. Throughout the exploratory research, the group has found that final agreed delivery dates are expanded during the negotiation process. The case company knows beforehand that even with such buffers, the settled dates are too compromised. Therefore, the representatives hope for changes, which will increase the lead time. The next step is the elaboration of a more detailed master plan taking into consideration the milestones defined in the previous step. At this point, different disciplines get together to discuss the main tasks needed for achieving each milestone. However, some engineers which belong to the electric and hydraulics disciplines are not part of these initial meetings and are involved later in the project. The plan is frozen during this stage and updated every month once the execution phase is initiated. The progress of the project is reported to the customer in accordance with the master plan.

The engineering phase starts with the reception of the customer's specifications. Most of them are hard to follow due to a high number of specialized standards where attention to details is of extreme importance. *"One single sentence of the specifications can jeopardize the entire project"* Project Manager (Interview Nov. 11th, 2015). The planning and control process related to engineering explodes the master plan into a product level where different drawing-packages are established based on the design review meetings. According to the interview participants, the biggest challenge at this point is to be as detailed as possible. The drawing packages are divided by each discipline leader into detailed activities with its corresponding due dates. These are the actual engineering activities to be performed, ending as pure deliverables. Due dates of drawings are critical because of the urgency to release them as soon as possible. In this context, a released drawing is understood as a deliverable ready for fabrication where the lead engineer is responsible and has full control over the activity. Released drawings are sent for procurement and fabrication to suppliers around the globe. The planning and control regarding fabrication includes receiving the planned activities from suppliers according to the milestones established in the master plan. The experience from different projects has taught the case company to buffer in terms of time, since these plans are unreliable. The report of performance (vs. schedule) from the suppliers focus only on critical items (e.g. the steal structure). Photographic evidence is the most common form of reporting. The photographs are aided by descriptions of what they have done as well as remaining tasks. Such reporting has shown not to be a reliable measurement for proper physical progress evaluation. Moreover, investigation for non completion is not performed, it is argued there is no time for it. The project manager follows up progress and performance, but reporting is only done when the customer requires an updated regarding project progress.

SI - Case company A

When a project is granted, both customer requirements and location give the company a good starting point on how to go further with the supplier selection. Hence, based on the requirements and consequently the characteristics of the end product gives a good initial argument for which supplier to choose as different products acquire different supplier capabilities. In fact, only two winches have been identical since 2004, which shows the low degree of standardization. Moreover, cost is also an important element to consider. The representatives of the company are always looking to balance these two variables (cost and location) when they choose suppliers. Consequently, suppliers usually change from one project to another. However, the representatives argue that there might be occasions when a reuse of a supplier is possible. However, a reuse of suppliers might not be beneficial as they usually demand more in the next project (Fabrication manager Interview March 2nd (2016)). During the supplier tendering phase, the company evaluates possible suppliers and their limitations. At this point, design might be developed with one possible supplier without being sure if they will choose this exact supplier in the end. There are huge differences between suppliers and some give ideas on how to improve design. "We try to cooperate, but its difficult. You have several suppliers at the same time. One supplier suggests one 'change' which makes its harder to compare the offers. It is not apple with apple any longer. The involvement of suppliers at an early stage can be tricky. Should the design be altered in order to make life easier for the supplier, when it might cause the design not be working in the future?" (Fabrication Manager Interview March 2nd (2016)). Other factors also play an important role at this stage which is why a considerable effort is done related to evaluating possible suppliers. Factors such as supplier capability, flexibility, prioritisation towards company and trust were mentioned as important elements to consider.

Capability is closely related to quality while flexibility is related to handling changes as a project progresses. Both factors are again affected by the supplier prioritization towards the company as well as trust. In fact, when a supplier is picked and not all information about the design is available at the early stages of a project has shown to be something suppliers might take advantage of at later stages. The perception is that suppliers can feel the dependency the company has upon them and try to take advantage of it in terms of cost. Therefore, the representatives of the company states that they usually hold back purchase orders in order to get a more defined workload for the suppliers. This is also evident for critical components such as the steel structure. Finishing all the design and engineering before fabrication would avoid many problems but a significant increase in lead time which the company cannot afford. In regards to prioritization, company A is small medium sized company and is not able to fill up a medium sized workshop and can be easily 'substituted'. Moreover, suppliers might consider the case company as a one time show, which might according to the fabrication manager affect their lack of commitment during project development. Nevertheless, it was perceived that there is a lack of a selection process with defined criteria. There are more assumptions being done regarding the suppliers than actually being sure of how they will perform. Thus, the company usually feels the need for on-site supervision of physical progress after production has started.

According to the fabrication manager, supervision is however not necessarily beneficial. It is argued that too much supervision generates costs both for the company as well as the sub-supplier without improving quality. It is argued that as supervision increases, the supplier might become too dependent on the client. The company has suggested to the suppliers that they can step down on supervision, but then the suppliers need to decrease their buffers. A successful case of a supplier relationship occurred in Korea with a winches manufacturer because an assessment visit was performed prior to the project to get an overview of the overall company performance. This led to alignment of expectations which enabled a positive outcome. Therefore the company did not have to fly over to the manufacturers site to monitor progress. In a way the sense of trust was generated.

5.1.3 Company B - Background

Case company B, just as case company A, is a Norwegian based ETO company in the maritime industry. Its operations focus on developing, designing and delivering a wide range of lifting equipment solutions for the offshore and subsea industry. In contrast to case company A, the solutions are done in cooperation with an strategic partner in charge of sales, services and delivering an integral final product such as an offshore vessel.

The different projects at case company B fall into one of three categories. Design project, design and delivery and delivery of previously designed solutions. The overall lead time varies depending on the type of project and the complexity of the final solution.

Regardless of the type of project, the project organization consists usually of the departments of project management, technical, mechanical and electrical engineering as well as other disciplines, such as design from the strategic partner.

Even though case company B is to some extent dependent on the strategic partner and with its growth projections, the company still outsource the production of physical components to suppliers around the globe. Hence, a role of value chain coordinators is still required for achieving competitiveness in the heavy lifting segment. Planning and control is seen as a serious mean for achieving competitive advantage by delivering the project on time, as it is considered the order winner (Project Manager Interview March 2nd (2016)).

Planning and control - Case company B

The starting point of any of the three types of projects in case company B is when a contract is awarded by the strategic partner. A preliminary plan is developed containing the main milestones indicating the start and end of the project. The latter indicates the delivery date of the final product.

The delivery date is the basis for a more detailed planning. Taking under consideration the master plan the next step is to determine a more specific plan including tasks and durations related to production such as steel structure fabrication, assembly and testing. The design work is defined based on the total production duration, meaning that the design and engineering workload must fit into the remaining time window (total time available to delivery date - duration of production). If the time window is sufficient, then the design will be completed ahead of production. In case the previous statement is false then, according to the priorities of different components, different due dates are given to design and engineering tasks. Considerations are given for the drawings of components which have long lead times in the fabrication process, for example the steel structure which requires the purchase of the steel one month in advance.

The design and engineer planning is divided into five phases which are delimited by a serial of approvals through the development of the drawings, ending with the production approval as *'built drawing'*. Depending on the workload, the drawings are rated in a scale from one to three, where the latter represents a drawing with a triple impact on the total progress of the design and engineering. The planning of production starts with sending the purchase order to the fabrication site with an attached predefined list of tasks taken from the detailed plan. The list of tasks is the basis for reporting the weekly progress of the execution of the component and an important element for updating the overall detailed project plan and master plan. Case company B asks the suppliers to develop a plan defining the due dates of the tasks in order to reach the delivery date of the component. In the circumstance of delays, these must be shown in the weekly plan update sent to the project management department of the case company alongside a root cause analysis and the corrective actions to be performed for keeping the promised due date. The project manager follow up the progress and performance of the project, reporting the progress on a regular basis to the strategic partner.

SI - Case company B

Supplier selection is a major topic reviewed every time a tendering process is initiated by the strategic partner. Depending on the type of project, suppliers are suggested from either a supplier base or new options are explored. For the projects where a completely new design is going to be developed, suppliers are qualified based on the criteria established by the case company and the strategic partner. Audits with the objective of assessing the capabilities of suppliers are conducted for new suppliers. However, it is a common practice to go for the preferred suppliers suggested by the strategic partner where aspects like trust and commitment have already been proven in previous projects. As a safety measure, the case company always keeps two or three options for the same component as a capacity buffer. Besides the intrinsic capabilities of the supplier, location and cost is also a decisive criteria for the final selection of the supplier. Components are produced around the globe and are logistically complex to transfer to the harbour for assembly.

All suppliers of critical components are selected early on in the project planning and according to the interview with the project manager, managing the costs and cash flow of the project gives clarity for the involvement of suppliers. Placing orders not earlier than needed is possible depending on the type of component, the maturity of the design and the relationship with the supplier. Through the case study it was clear that the case company considers SI as the degree of responsibility which affects the frequent communication with its suppliers and the timing of the interactions. For instance, the case company recognizes that suppliers of the critical components like the steel structure require to be early involved in order to achieve DFM for avoiding future issues. In addition, their good relation with the suppliers promotes the effort of making suggestions in regards to DFM even when the contract has not been given to the selected supplier. According to the case company, a good relation counterbalances the low buying power, trying to emanate a prioritization effect. For example, relative minor changes that might add some extra work, are not seen as a problem by suppliers.

The case company sees involvement of suppliers as a planning oriented task, where the objective is to plan with them rather than for them. In order to plan with them, suppliers need to explode the main tasks derived from a master plan and being themselves the one who propose the due dates in agreement with the case company. The previous planning strategy has reflected improvements in the reliability of delivery dates (Project Manager Interview March 2nd (2016)). A rigorous weekly update of the production plan must show the progress. This reporting must be done before the weekly meeting, an essential element of a fixed agenda throughout the project. In the circumstance of delays, these must be shown in the weekly plan update alongside a root cause analysis and the corrective actions to be performed for keeping the promised due date. Based on the input information from the supplier, the case company can frequently update the overall plan, reflecting any changes and deliver a trustworthy report to the strategic partner.

One of the key elements for diffusing trust with the supplier has been an extensive support by sending engineers and supervisors to the supplier's site, specially when it is a new development or the supplier has recently been added to the supplier base. According to the past experiences of different projects, this activity should be taken with caution as suppliers can become dependent on the engineer or supervisor.

5.1.4 Summary of case studies

The empirical study has gained insights into how project planning and control is conducted in two Norwegian ETO companies involved in the design, manufacture and installation of highly complex heavy-lifting equipment to the offshore industry worldwide. The main emphasises has been dedicated to how their sub-suppliers are involved throughout a project in regards to project planning. A summary of the planning and control characteristics in each companies follows.

Company A

- Master plan considering different disciplines developed by sales department
- Plans in all levels are updated in some cases when needed and with pre-set dates (lack of dedicated resources for planning)
- Low degree of collaborative planning (fading away once planning becomes more specific) leading to an unreliable plan
- Suppliers are involved sporadically in early stages and dispersed around the globe

(usually changing from project to project)

- Weak focus on constraints removal
- No time is given to continuous improvement
- Meetings occur with the purpose of solving problems rather than planning
- Project performance reporting at top management level is elaborated mainly as a requirement from customers (no proper physical progress measurement is performed)

Company B

- Master plan discussed with several departments with a strong focus on the delivery date
- Delivery date is the base for detailed planning performed backwards in reference to the overall project duration
- Plans are updated on a well defined time horizon
- Critical suppliers are involved by presenting a short-term plan of the components to produce (usually preferred supplier are used)
- Strong focus on continuous improvement
- Project performance reporting to strategic partner is done on a regular basis

6 | Discussion

The following chapter outlines and discusses the overall findings and contributions in the master thesis. The related findings are discussed in light of the literature, as well as weaknesses and limitations of the findings.

6.1 ETO SC coordination

Literature has shown how a considerable coordination effort is essential in order to successfully deliver projects in an ETO SC. The engineering-production interface is seen as the two main fundamental functions which are directly involved in fulfilling customer needs. Coordination between such interdependent activities has by far gathered most attention and is consequently highlighted in literature as the core issue in regards to improving the overall performance in an ETO SC. In other words, competitive advantage emerges from the ability to coordinate internal and external processes. This is in line with the observations in the empirical study where both companies A and B have realized the need to take roles as global value chain coordinators as a huge part of their physical value creation, thus the greatest opportunities for improvement are handled by other actors. However, several factors have shown to affect the efficiency of such cross-business activities. The empirical study showed how both companies have recognized the implications such factors might have on the overall project performance, which is highlighted in literature as essential in order to address effective solutions regarding coordination (McGovern et al., 1999; Hicks et al., 2001; Pandit and Zhu, 2007).

6.1.1 Factors affecting coordination

The empirical study led to the identification of several factors affecting coordination. The fact that both companies operate in similar environments consequently leads to the identification of similar factors. These factors reflect the factors found during the theoretical study, previously presented in table 3.8 and discussed in light of LPS theory (section 4.1). In essence, it can be seen that such factors arise due to the overall characteristics of the ETO environment. Hence, some factors are not necessarily avoidable, which showcase the numerous of challenges which need to be handled throughout an ETO project. Five factors were identified during this master thesis:

- High level of uncertainty
- Overlapping engineering and production
- Maturity of the design technology
- Geographic dispersion
- Production capability

One major challenge in ETO manufacturing is the low level of specification during the early engineering and design phases, which consequently lead to a *high level of uncertainty* in product and process design. This is very much the case for both companies in the empirical study which deliver a wide range of lifting equipment solutions with limited standardization to the offshore and subsea industry. Moreover, literature has shown how production might even start before design is finished in order to reduce the overall project lead time. Both companies A and B are dependent on *overlapping engineering and production* activities in order to deliver on time. The low level of specification increases uncertainty as it usually results in frequent changes. Such downstream changes usually generate production changes as well due to the low *maturity of the design/technology*. Moreover, the overlapping of activities when not all information is available increases uncertainty even more and engineering changes becomes especially challenging. Therefore, such overlapping might have an opposite effect resulting in an increased lead-time. Literature has shown how coordinating such changes becomes a major challenge and that good communication between entities becomes crucial. However, *geographic dispersion* between entities due to the high level of outsourcing has been highlighted in literature as a factor that counteracts the ability to achieve this in practice. As seen in the empirical study, both companies A and B outsource all production of physical material. Overall, coordination has been seen to become even more challenging when the focal company has low dominance over the activities performed. The increase in interdependence has stressed the need for mutual adjustments between plans and objectives. However, conflicts due to different perspectives on value, priorities and culture as well as frequent mistrust between entities has shown to be an outcome of multisourcing activities. These observations from literature are also reflected in the empirical study. Company A stated that suppliers tend to take advantage of missing information at later stages of the project. Therefore, company A usually holds back purchase orders in order to get a more defined workload for the suppliers. This is also evident for less mature products from the main sub-suppliers. Moreover, low prioritization has also been a frequent problem. Company A is a small medium sized company and is not able to fill up a medium sized workshop and can be easily 'substituted'. This showcases how *production capability* becomes a critical factor affecting coordination. In contrast with company A, it became evident that company B has a more structured selection process with defined criteria. Frequent audits of new suppliers performed by the strategic partner enable a lower degree of uncertainty in regards to prioritization, commitment and trust.

The theoretical and empirical study has shown how such factors aggravate each other, meaning that one factor might affect the ability to overcome challenges which derive from another factor. On the other hand, overcoming such challenges might ease the impact from other factors and consequently increase the desired coordination. Altogether, the question about the factors that end up affecting the ability to coordinate cross-business activities in practice has not a straight forward answer. This has also been demonstrated in the empirical study. Both companies operate in similar environments and are initially exposed to the similar factors and challenges. However, the impact from such challenges on the overall coordination effort has shown to be different between both companies. In fact, the empirical study revealed a significant difference between the companies' planning and control routines in order to cope with the many challenges affecting coordination throughout a project. Hence, how planning and control is utilized in practice, affects the ability to coordinate cross-business activities, such as engineering and production. A supplier-oriented LPS framework was previously presented (section 4.2) as a suggestion to achieve such coordination in practice.

6.2 A Supplier-Oriented LPS framework

The objective behind the proposed framework is to provide a suggested solution to the planning and coordination problematic encountered by many organization with an ETO profile in high cost manufacturing countries which outsource production. In this section, implications of the framework as a whole and its constituent components will be discussed with the empirical data collection and in light of literature. The purpose is to add validity, realism and investigate the possibility to turn the framework into best practice.

It has not been long ago that researches in the fields of SCM, project management, coordination and SI recognized the awakening of project planning as the mean of structuring the coordination mechanisms in the proper time and mode during project development. This structuration is required to handle the coordination complexity in ETO projects with outsourced production. On one hand, the unprecedented complexity resides in the separation of the two most important phases in this type of projects, engineering and production. Moreover, production faces the issue of shared production units, where the needs of the focal company managing the project are not necessarily prioritized as well as having low buying power over the supplier. On the other hand, SI theory has shown significant improvements in different organizations, increasing their competitive edge. Even though SI theory arose from an environment where the focal company has high buying power, it provides specific tasks that have shown to improve coordination and are not necessarily dependent on the prioritizing or high buying power. Overall, in the conducted literature study the exact allocation of such SI tasks in a planning process was not found. Nevertheless, early involvement of suppliers in the design phase was consistently mentioned and foremost the most specific placement of such related tasks. The marriage of a project planning method like LPS and SI tasks based on the allocation of such tasks in each of the phases of LPS, leads to a strategy for providing the adequate timing of the SI. The idea behind this union is to provide the best coordination effects between design/engineering and production, where *planning for* the supplier is left behind, superseded by *planning with* the supplier. Each phase of the planning process is chronologically presented with the related tasks.

Master schedule

Regardless of any planning method a project manager decides to apply, the definition of gross milestones is the most basic shared step among the diverse methods. The reason behind giving such an important distinction to this initial stage is according to Emblemsvåg (2014a) and Ballard and Howell (2003a) an important step for indicating the final delivery time of the product, affecting the production planning and consequently the order fulfilment plans. The empirical evidence from both case companies showed the milestone process as the first step towards the project planning. However, research concerning project planning pinpoints how several ETO organizations have considered project planning as a static process resulting in a frozen Gantt chart performed by a single group, usually the project management team. A frozen chart incites to a deficient communication between all parties involved in the project, leading to an initial pitfall towards coordination. This is in line with the findings in case company A, where only the sales department sets the master plan containing the main milestones which lead to negotiations with the client that would influence the production order plans. On the other hand, case company B discusses milestones with several departments, giving special attention to the end date of the project as it is the basis for a more detailed planning.

The nature of the environment in which the outsourcing ETO operates gives a straightforward indication that production of the main components represented by suppliers in different parts of the world needs to be involved at early stages of the project planning.

The question many researches have tried to answer resumes to how early involvement is achieved. Suggestions have been introduced by the automotive sector where SI theory had its main development (Takeishi, 2001; Wagner and Hoegl, 2006). Among these suggestions, one of the actions constantly repeated and which is related to the multiple SI definitions is the supplier‘s capabilities. The previous statement was confirmed in the series of conducted interviews with both case companies and during the organized workshop (Workshop March 8th, 2016). In fact, capabilities for delivering a product matching the requirements of quality, cost and delivery time were appointed as the first thing organizations should look for in a supplier (Vonderembse and Tracey, 1999).

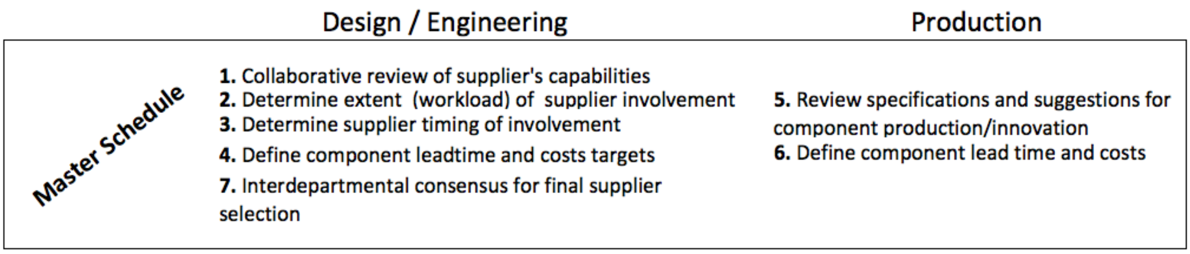


Figure 6.1: Master schedule tasks

Therefore, the first activity (task 1) of the master schedule in the presented framework is to review the supplier's capabilities collaboratively with all the departments. Such capabilities should best suit the specific needs of the project as different projects might need different competences from the supplier. Note that task 1 is a review since an audit or other type of assessment should be conducted before the LPS planning process. In fact, case company B gets support from the strategic partner which audits the possible suppliers for diverse projects. This has according to the project manager resulted in a well developed supplier base. Looking into supplier capabilities in LPS was not considered as crucial since, according to its creators, the reliable flow principle in which it is based generates a streamlined project execution. The analysis regarding LPS applicability indicated that the capabilities of suppliers should be considered when production is outsourced as there is no guarantee for prioritization from the suppliers. During a presentation related to

LPS as part of the organized workshop, a former manager from a Norwegian shipyard gave the example of how the components needed for a vessel were not prioritized by the suppliers from Asia as they were serving other clients with more extensive purchase orders (Workshop March 8th, 2016). It is understandable that the original approach of LPS does not include such review of suppliers, as construction projects have exclusive and committed partners on the site. However, this is in complete contrast with the situation in which the case companies are involved in.

Besides the review of the capabilities of potential suppliers, the focal company needs to decide at this early stage the workload that will be given to the different suppliers (task 2), even though they have not been finally selected. The degree of novelty of the product and the degree of analyzability as part of the uncertainty needs to accompany the competences to determine the workload. These two aspects are in line with the product/process fit introduced by Adler (1995) and the positive correlation found by Primo and Amundson (2002), relating capabilities and extent of SI. Even though both companies are aware of the implication of the high novelty and low degree of analyzability, it seems not to be clear for company A how this awareness can help them to clear the panorama for giving assignments to suppliers. For case company B the roadmap is less blurry as it mixes the three variables, competence, product innovation and analyzability. As seen in theory, timing and involvement are intimate linked. Setting the proper amount of workload gives a semi-automatic timing of the involvement of suppliers. It is semi-automatic since other aspects like intellectual property and financial issues can override the timing. During the workshop it became clear that organizations were misunderstanding the timing of involvement with a more purchasing oriented definition, in which timing was linked to the purchase order. In this framework, the timing of involvement (task 3) is more oriented towards an increased understanding of uncertainty for improving coordination early in the planning process.

Task 2 and 3 leads to the definition of targets related to lead time and costs (task 4) that attempt to give a suggestion for enhancing the initial commitments of delivering terms. By setting targets, suppliers will have a broader perspective of what the focal company is expecting which can potentially reduce conflicting objectives early in the project. While the previous tasks are executed, a review of specifications is expected to be conducted by the supplier (task 5), presenting suggestions on the component they intend to produce. Case company A asks for suggestions regarding all the bidding suppliers for the same component with an aim to put DFM into practice. However, different suppliers suggest different changes and the chaotic exchange of suggestions makes it difficult for company A to compare the offers. The dilemma could be less chaotic if company A could implement consistently an in depth assessment and review of the supplier's capabilities (task 1), at least for the critical components. Evidence from the empirical case study showed that such an assessment has worked for them in the past with a winches supplier in Korea. For case company B with its strong supplier base, the suggestions coming from the suppliers has become a habit present in every project. Company B argues that standardized design can be sent to almost whoever. However, for more complex design, suppliers should be involved. This is in line with the observations in the literature study where proactive involvement of suppliers early is considered important as a huge part of the contract value is controllable at the design stage (Burt and Doyle, 1993).

The different suggestions for the components to be produced also imply defining lead time and costs targets (task 6) that must relate to the targets established by the focal company. The accuracy and honesty of the lead time estimates have a magnifying impact to the master schedule phase, as the main objective is to give the overall delivery date. The literature study revealed how LPS master schedule theory is not as extensive compared to the other phases. However, in ETO companies like the ones studied in this thesis, definition of lead time has two major implications. Firstly, it is an aspect that can make an organization win a contract. Secondly, it is a clause included in the contract since any delay of delivering the product results in a delay in the overall end product. A typical example could be an offshore vessel.

The presented sequence of activities in the master schedule stage has as its end goal to select the most capable supplier to cope with the different conditions during the execution of the project. Capabilities, amount of workload, timing of involvement, proposed lead time and cost, plus location, as both case companies introduced, are all in summary the variables that needs to be balanced before deciding to go for a certain supplier (task 7). As many participants of the workshop mentioned, selecting a supplier responsible of a critical component is like selecting a partner with an accelerated development which has high probability to be dismissed after the project is ended, despite its demonstrated effort (Workshop March 8th, 2016).

In general, the tasks presented give support to the analysis conducted where it was established that there is room for improvements in the early planning phase of LPS. Moreover, the master schedule stage is coherent with literature in the sense that most of the SI tasks are concentrated in early phases of the planning process. The master schedule as it is presented in the framework aims to be executed during a tendering phase and beginning stage when the contract is awarded. However for some organizations this master schedule is performed once a contract has been awarded.

Phase schedule

The phase schedule in LPS represents an explosion of the master schedule, nothing different from any other project management techniques. Nevertheless, the compulsory gathering of a committee from each of the different parties creates a coordination and communication pattern as mentioned in the *LPS applicability* section. The generation of this pattern contributes to give the thread for separating the master plan as a plan per se, to phase scheduling as a planning process. The second contribution relates to the most overall intention of coordination and SCM theory, aligning the goals and objectives to improve the SC performance. Therefore, during the phase scheduling process it is of great significance that the focal company guides and remarks to the SC entities the aim of the project and that the generated project network diagram showing the hand-offs is collaboratively agreed and understood (task 1). As LPS theory indicates, the requirement for successfully performing a reverse scheduling based on project networking is a gross constraint analysis (task 2) and lead time information.

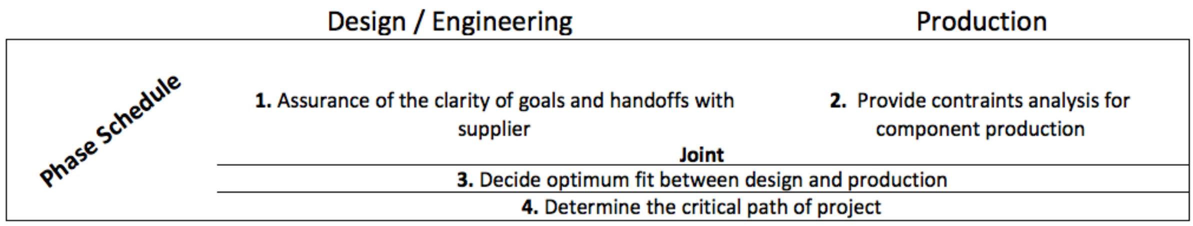


Figure 6.2: Phase schedule tasks

The constraint analysis must come from the supplier, otherwise the phase schedule looses its value and contributions. The empirical study on case company B showed how a close resemblance to phase scheduling is preformed in practice. The project management team set a more detailed plan based on the durations of the fabrication of critical components and then a schedule was generated backwards in relation to the overall project duration.

Ballard (2000), based on the inspirational work from Koskela (2000), introduced how product and process could be designed simultaneously. The overlapping phases (ref. figure 3.2) in LPDS set the background for a design and production fit. The fit is in simple words the action of considering the criteria, concerns and limitations of the production process in design. According to LPS literature, it is only by extensive communication and reaching an agreement how these elements can be performed simultaneously. Moreover, the phase scheduling stage has the goal to specify the different processes that will decide the fit of design and production. The negotiation forum provided by the phase scheduling gives the stage to decide as a group an optimum fit (task 3) that will give a win-win situation for focal company and suppliers. This collaborative decision for finding a solution is in line with Galbraith (1973), indicating that in order to reach a higher degree of coordination effort to handle the diversity and uncertainty of interdependent activities, a consistency of the decisions made is required.

The research of Hicks et al. (2000) enlisted a series of reasons for differentiating buyer-supplier relationships. The proximity to the critical path was considered as one of the most important when a low degree of vertical integration is the main feature in a project. Moreover, Hartley et al. (1997) warned how a special attention regarding suppliers of critical components needs to be considered since most of them fall into the critical path of the project and are usually not exclusive, meaning a lack of prioritization might happen. For Winch (2006); Lindhard (2013b) and Kerzner (2013a) it was surprising how the critical path concept and consequently the critical path method and critical chain method were omitted in LPS. The three researches coincide that critical path in a project is a leverage point to achieve the reliability of delivery of the final product. It can be discussed whether LPS does not require such mechanism as the theory of flow provides the reliability. However, the critical path could be considered as a type of insurance if the suppliers decide not to fully comply with LPS methodology. After performing their reverse planning, the critical path of case company B is identified which will lead to different task prioritization. The phase scheduling process in LPS is halfway of performing an critical path analysis. After discussing the project network with the reverse scheduling, collaboratively the critical path can be determined (task 4). The main reason for including critical path in LPS is as a measure for better handling the risk of prioritization uncertainty between high interdependent activities handled by independent organizations.

Look-ahead plan

The look-ahead plan is the stage in LPS that brings most of its advantageous proposals such as postponement. Furthermore, it is where activities are starting to be transformed from *'Should'* to *'Will'*. Postponement implies getting into detail just weeks before the execution and not before making the planning friendly to changes and easy to update. As the time for execution approaches the phases are decomposed into task packages (task 1).

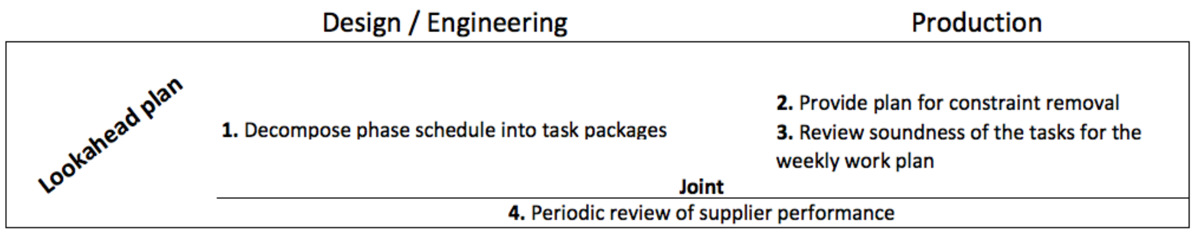


Figure 6.3: Look-ahead planning tasks

In the phase schedule, entities responsible for a component were asked to provide a constraint analysis, basically showing all possible constraints to remove in order to deliver the component. In the look-ahead plan, a plan for removing those analysed constraints (tasks 2) needs to be proposed and communicated (Hamzeh et al., 2012). The time for removing all constraints is the time window given by each organization to its look-ahead plan. The authors of LPS recommend three to twelve weeks. The empirical study showed how case company B asks their suppliers to propose them a short-term plan regarding the production of components. Such activity is only asked to the suppliers of critical components or the ones that fall into the critical path. This activity performed by case company B resembles to the idea of a look-ahead plan and gives evidence on how LPS principles have worked in successful projects outside construction. Since LPS theory is open towards which entity is fully responsible of the look-ahead planning, inspiration from the best practice of company B is taken into consideration for redefining the proposed framework at the look-ahead stage, including a task in which each supplier is responsible for providing a short-term plan regarding the production of components.

The proposed task (3) of reviewing the soundness of the buffered tasks ready to be execute arises from the criticism of Lindhard (2013b). The main argument is based on how information and processes can affect the constraints of an activity that could have already been considered as ready to be executed. The previous statement is supported by the high uncertainty experience by the ETO organizations during project development. Therefore, this activity was included under the responsibility of each supplier to perform a review of its make-ready tasks before going ahead and elaborate the weekly work plan. Another strong criticism LPS received is alluded to the unclear linkage from bottom to top planning (Junior et al., 1998). This means a lack of straightforward link between the weekly work plan and the master schedule for reflecting the situation at each moment against the overall planning. According to the planning process of company B, the weekly progress reported by the suppliers is an important element that allows the update of the master plan. Such update is according to the project manager a requirement for constant progress and performance reporting asked by the strategic partner. The previous common practice in case company B provides a suggestion for mitigating the criticism of LPS. Therefore, a task of reviewing and updating the supplier's short term plan is proposed as an enhancement for the look-ahead section of the suggested framework.

Vonderembse and Tracey (1999) mentioned that a high performance SC constantly measures the performance of suppliers throughout the project. Usually, the base of such performance assessment is centered around the targets and criteria defined at the master schedule stage. The amount of target deliveries, quality misses and different cost indexes should be reported. Besides being an enabler to increase joint performance, a periodic assessment is needed for a better management of the supplier interface in the organizations with a low degree of vertical integration. This task is proposed to be accommodated in the look-ahead stage because of the time window offered. However, it is up to the focal organization to conduct the assessment.

WWP

The second main component in LPS alongside the look-ahead planning process gives the opportunity for the different entities in the SC to decide their own production schedules (task 1). The sense of freedom implies a higher degree of responsibility and commitment which attempts to increase the overall collaboration effort. The WWP plays a key role in the project performance as the reliability of the lead time depends on the reliability of the production schedules. Furthermore, the WWP could be considered as a production phase coordination mechanism due to its origin from a series of planning stages and activities which have considered the coordination needs. It is only by complying the chronological development of LPS that the production units, in this case the suppliers, can be shielded against the uncertainty around the project. To some extent, every supplier as an independent organization could generate production schedules with tasks that at this point in the planning process are constraint free. However, the challenge is to make sure that the supplier's production schedule sticks to the short term plan represented as the look-ahead plan due to the fact that the supplier might also serve other clients. Therefore, it is necessary that the supplier reviews and updates on a weekly basis the production schedules against the short term plan (task 2).

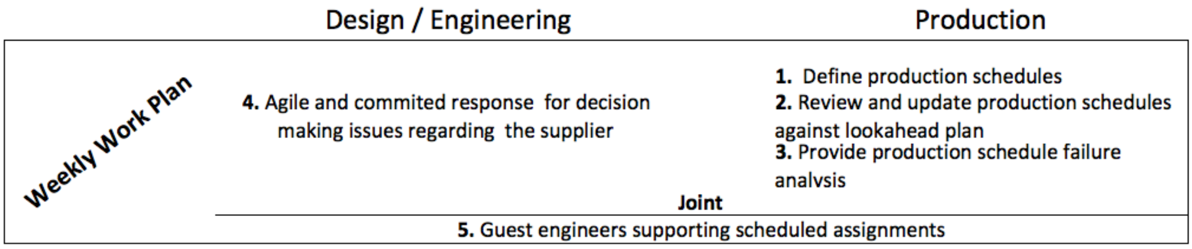


Figure 6.4: Weekly work plan tasks

In regards to case company A, the update of progress is focused on critical components. Photographs are the main mean for showing the progress and are according to the interviewed staff not a reliable measurement of the physical progress. In addition, the reporting is not done consistently and only when the customer requires it. For case company B, reporting the weekly progress is a mandatory assignment for the suppliers and it is based on the plan sent by them.

The repetitive success in LPS could not have been achieved without a learning process. Continuous improvement is a major pillar in LPS, a naturally expected ingredient from a planning method embedded in the lean philosophy. The WWP stage enforces a production schedule failure analysis (task 3) for those tasks that were not completed during the scheduled week. For some organizations like company A, it is complicated to perform such analyses because of the lack of resources and time. In contrast, suppliers of case company B dedicate a section of the mandatory weekly reporting to a root cause analysis and include the corresponding corrective actions.

An agile and committed response for decision making issues (task 4) represents the first step into a cordial relationship where the supplier feels backed up against the *"imposed demands"* by the focal company. The need for enhancement in this area was identified in the empirical study in regards to the way case company A would only call for meetings when distress appeared on the horizon and decisions would have to go through a series of approvals. Overall, task 4 in the presented framework attempts to counterbalance the low buying power. It is important to remark that this activity is cyclical throughout the WWP and not necessarily following a sequential order.

The matrix of Adler (1995) displays the typology of coordination mechanism and gives insight for the type of mechanisms companies like those presented in the empirical study should strive for. Regarding the production phase, transition teams are suggested as the ultimate mechanism for handling the most demanding coordination effort. The suggestion from theory has been taken into practice by both case companies. On-site guest engineers supporting the schedules assignments (task 5) have been demonstrated as a measure to improve coordination and trust development, specially when the focal company has never worked with the supplier before or its a totally new development. However, evidence has also shown how such supervision might have the opposite effect. Both case company A and B stated that the suppliers might become too dependent on the guest engineers. Such supervision therefore need to be evaluated based on the situation.

6.2.1 Re-defining the Supplier-Oriented LPS framework

The supplier-oriented LPS framework brings together LPS with SI theory establishing how coordination is a information processing activity. In the previous discussion the *planning with* the suppliers has proven to initiate a structured road for preventing the habits that have aggravated the uncertainty and other contextual factors in ETO projects. The conducted comparison of the planning and SI activities of the case companies with the proposed conceptual framework has uncovered tasks which have been adding value to multiple projects. The vast project experience from the organizations have been taken into account by including the uncovered tasks into the framework and therefore turning the framework closer to best practice. Moreover, the diverse criticism towards LPS, unraveling its areas of improvement for a better translation towards environments outside construction, have also been taken into consideration in the formulation of the framework.

The master schedule, phase schedule and WWP with their corresponding activities practically remain the same while the look-ahead plan has most of the modifications. The first task in the sequence of activities is established as the production responsible for defining the production schedules rather than design responsible for the task packages. In addition, reviewing and updating the supplier's plan against the phase schedule and master schedule (task 4) was taken as a valuable input from the empirical case study. Figure 6.5 presents the re-defined framework considering the inputs from discussion.

6.2.2 Potential barriers and limitations

LPS is heavily affected by the environment and the people within the organizations, which consequently brings barriers to the proposed framework. The conducted analysis regarding LPS applicability to improve coordination in an ETO SC has showed promising results. However, as previously discussed, the reliability of commitments from the different entities in the SC are outside the control of LPS where trust, which is not achieved from implementing LPS, becomes an important element. The possible pitfall is related to how LPS might fall into another bureaucratic buffer method without trust-based relationships and two way communication.

The proposed framework does not cover all aspects of a typical project in the ETO sector. Assembly and testing are also two main stages which should be taken into consideration. However, the importance of design and production coordination early in the process, might reduce the coordination and involvement in later stages. This is in line with both, the empirical study and the organized workshop, where high involvement at later stages was seen as undesirable. In addition, late involvement often arises due to poor planning in the initial stages.

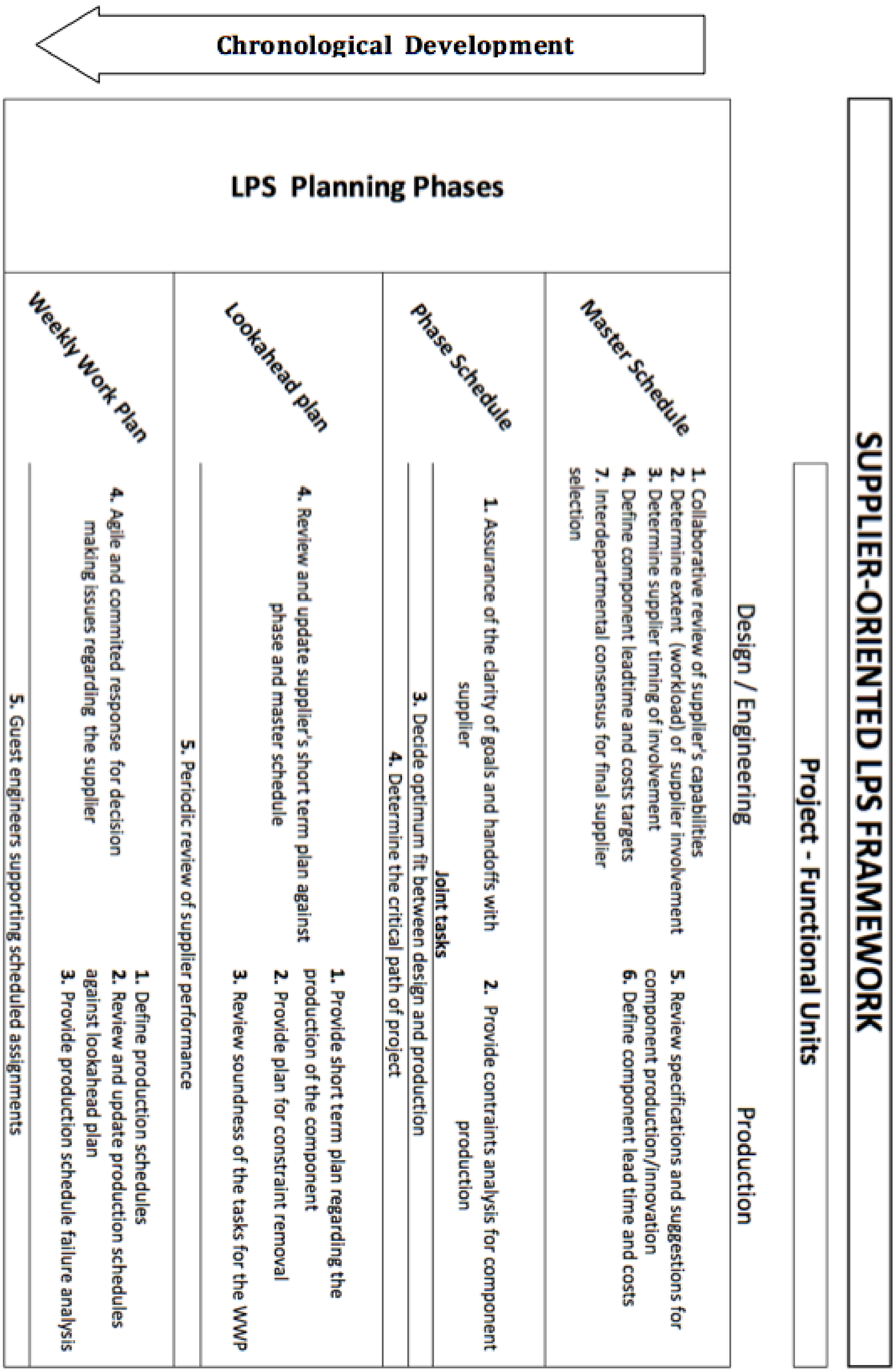


Figure 6.5: A Supplier-oriented LPS framework - re-defined

7 | Conclusion

This chapter presents the overall conclusion based on the findings from the previous chapters. These overall implications are followed by a description of the implications for theory and practice, research limitations as well as suggestions for future studies.

Within the ETO sector, outsourcing of production has increased the coordination effort needed. Coordination mechanisms have been proposed and set into practice in order to increase the required coordination. However, the selection criteria regarding the mechanisms has lacked an analysis of the factors that affect coordination. It can be concluded that without looking at the factors affecting coordination that corresponding to the context of each organization and its projects, the mechanisms will not generate the expected effect to handle the required coordination between the SC entities. Moreover, less focus has been dedicated to how such mechanisms can be implemented and utilized in practice.

LPS has demonstrated success as a lean project planning method to cope with the characteristics of an ETO like construction. However, similarities between ETO organizations like construction and the companies within the scope of this thesis are not enough to conclude that LPS will generate the expected coordination effects. An analysis between LPS and the observed factors affecting coordination was conducted. The conclusion provides an overall positive resolution to how LPS can overcome the factors affecting coordination and the implied challenges between the entities in the ETO SC. Moreover, this conclusion provides an initial argument on how LPS is able to structure the implementation of the coordination mechanisms in practice. Areas of opportunities were identified, where most of the required improvements relates to the involvement of suppliers and their specific participation throughout the project.

A supplier-oriented framework has been presented based on the union between the LPS stages and specific SI tasks with the objective of providing the best coordination effects between design/engineering and production, where *planning for* the supplier is left behind, superseded by *planning with* the supplier. Furthermore, the empirical analysis, matching the framework with activities performed by the case companies, draws the conclusion that several activities in the framework are performed by these organizations making the framework a potential best practice.

7.1 Research questions

Research questions	**Results**
RQ1: What factors affect coordination in an ETO SC?	Five factors were identified during the conducted literature study (section 3.3.2). In essence, it can be seen that such factors arise due to the overall characteristics of the ETO environment. Hence, some factors are not necessarily avoidable, which showcase the numerous challenges which need to be handled throughout an ETO project.
RQ2: How can LPS overcome the factors affecting coordination between entities in an ETO SC?	The theoretical analysis conducted in section 4.1 implies a promising alleviation of the challenges related to the factors affecting coordination. The analysis enlightened the feature of LPS to structure the coordination mechanisms in practice. Areas of opportunities for enhancing the applicability were identified, where most of the required improvements relate to the involvement of suppliers and their inherent characteristics.
RQ3: How should suppliers responsible for production be involved in the planning process of LPS throughout a project?	The theory related to SI provides specific tasks which can increase the competitive edge due to the coordination effects these activities generate (section 3.5.4). However, SI theory has not been clear on how suppliers should be involved throughout the whole project development. A conceptual framework has been proposed and intends to define the SI contributions in the planning process of LPS. It is based on the LPS planning and control method from the Lean Construction Institute (LCI) and SI literature. (Further discussed in section 6.2)

Figure 7.1: Research questions and results

7.2 Implications for theory and practice

This research aimed to highlight the potential opportunity for integrated planning and control as the umbrella for structuring the implementation of the coordination mechanisms in practice appropriate for the coordinating effort required.

LPS was designated as the planning and control method to face the factors affecting coordination, resulting in a positive resolution by enabling implementation of the adequate coordination mechanisms. Areas of opportunities regarding the involvement of suppliers responsible for production were identified to expand the argumentation behind LPS and coordination effects.

This research set the base for a solution regarding the most essential coordination interfaces in ETO projects, design/engineering and production. The solution compels and unifies in a conceptual framework the knowledge from the collaborative planning and control method (LPS) and SI literature. The suggested framework can be used by the focal company with their suppliers to perform sequential group activities that will increase the coordination among these two entities, increasing the reliability of the project planning and therefore lead to reliable project delivery time.

7.3 Research limitations

The master students can not be completely certain about the empirical evidence. There might be some errors related to the data collection and the way the students interpret this data. However, it is reasonable to assume that the data is accurate to a large extent as it has been discussed with researchers in the LIFT program. Moreover, there was also a significant difference between the companies in regards to answering certain questions. This may be in part due to some ambiguity in the interview questions and also due to organizational planning procedures and knowledge. A more in depth case study of the companies could give a more accurate perception of the planning environment and potentially strengthen the robustness of the framework.

Suppliers have not be interviewed during this master thesis due to financial reasons as well as the limited time available. The proposed framework focuses on tasks between the engineering company and the suppliers responsible for production. It would have given valuable insight to the validity of the tasks by also interviewing the suppliers responsible for production.

Caution should be taken in generalizing the findings of this study to all ETO companies. Since the planning routines of other ETO companies can differ, studying these ETO companies could give valuable input to the framework.

7.4 Suggestions for future studies

A quantitative analysis of ETO companies, where a measure of how the degree of utilizing the specific tasks in the framework affect business performance could be done. This could help establish best practice for industries. Moreover, how information should be shared and exchanged between entities has been out of the scope of this master thesis and should be further investigated. This would be required in order to implement LPS in practice. Moreover, as LPS is a human based system, it should be tested in practice in order to make final concluding remarks regarding applicability.

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8 | Appendix

8.1 Norwegian Ship Equipment Industry

Eleven out of nineteen Norwegian counties have a wealth creation of more than NOK 500 million from the ship equipment manufacturing industry.

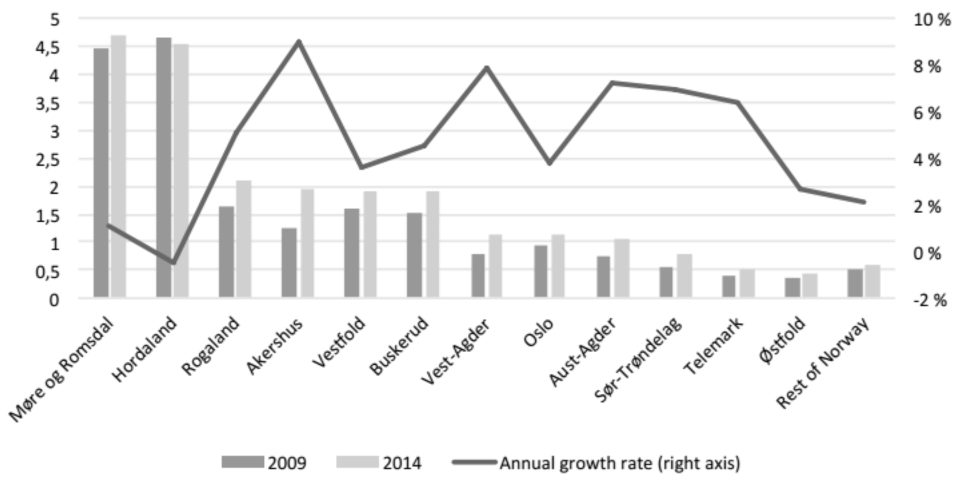

Figure 8.1: Wealth creation in 2014, by county, and annual growth in wealth creation over the past five years (Menon Business Economics, 2015)

8.2 Interviews

8.2.1 Interview 1 - Company A

PhD student Gabriele H. Jünge was leading the discussion followed by researcher Mikhail Shlopak and Espen Rød, both employed at Møreforskning Molde and active project participents of the LIFT research project.

From the case company the following people participated at the interview: Head of project department and project manager, head of fabrication/procurement and head of quality department.

Interview Questions

The questions were written by Erik Matthias Erichsen and Jorge Eduardo Cordero and given to the interview participants. The answers are not included, as they are the foundation for the planning and control environment in the case company, section 5.1.2).

1. Could you describe in general terms the engineering and manufacturing planning processes for a crane? How do you come up with the project's lead time? How do you elaborate your budget of the project in terms of hours and cost?
2. What are the challenges of the planning and control processes?
3. In which stages of your process from order request to delivery, significant variability in the flow of information and materials occur? Why does this variability happens?
4. What are the requirements to release a task to suppliers and workers? How is the interaction and involvement with the suppliers and customers when it comes to planning a project?
5. When do the milestones in the master plan (if they have) turn into detailed work packages?

6. How often do you update your planning? Is there is any meeting where commitments are established? Do people come prepare to meetings?

7. How do you control the production? How do you evaluate and measure your production plan?

8. In a rough terms, what would you say is the percentage of failure of projects in terms of time, budget or quality due to poor planning and control? Are the reasons for non-completion of tasks investigated further to prevent it from happening again?

9. Would you say is more costly to deliver days / weeks later than planned or increase resources and other elements to finish on time? How is manning performed?

10. Have you experienced that greater progress are reported than what is the case? If so, what was the consequences and when do you usually notice?

11. Form project and project, do you change a lot of suppliers? What type of relation do you have with your different suppliers?

12. Could you describe the product development process at?

8.2.2 Interview 2 and 3 - Company A and B

1. Could you describe the main phases of a project?
2. What would you say made the difference between a successful project and a project that didn't fulfilled the established objectives (cost/time/quality)?
3. What is your perception of the term 'supplier involvement'?
4. How many suppliers are usually participating in a typical project?
5. What do you consider (criteria) when you choose a supplier for a certain project?
6. Is there a clear distinction between supplier roles and level of involvement?
7. How active are suppliers in the development of products?
8. Does the company strive to establish long-term relationship with suppliers. If not, why?
9. Do you consider close communications with suppliers during a project?
10. From your experience, where do you think supplier involvement could be useful and in which degree? And how is it related to fulfilling customer requirements?
11. What would you say are the challenges for involving suppliers during the different stages of a project?
12. How are you monitoring your suppliers during a project? How do you know your suppliers is on schedule?
13. How are the supplier relationship managed internally during a project?

8.3 Workshop exercise - Managing supplier involvement

Molde Lifty AS (est. 2010), is becoming a leading actor in the heavy lifting industry after many successful projects in the recent years. Design and engineering activities are seen as the company's core capability.

Almost 90 percent of the overall turnover comes from projects outside of Norway, which gives a strong signal of how Molde Lifty AS is exposed to considerable international competition. Even though the market activity has dropped the last couple of years, Molde Lifty AS has a growth ambition in their segment of the market. However, the organization has realized that in order to stay competitive in the long term, they need to take the role of global value chain coordinators, as a large part of the physical value creation is outsourced.

Exercise 1

One of the main goals for the case company presented in this text is to achieve the best coordination among the entities in the value chain. As a team, define 5 ideal attributes strategic suppliers must possess in order to fulfill the established goal. Once the list is defined, prioritize according to the degree of importance for achieving such coordination. Feel free to make the necessary assumptions.

Exercise 2

Molde Lifty AS has recently landed a huge contract. However, the company recently lost its main strategic supplier of steel structure (workshop) as one of their main competitors decided to vertically integrate. Hence, this supplier is no longer available. Nevertheless, during the initial stage of the project another steel structure supplier was located. During the selection process it became clear that this exact supplier is matching the overall attributes set by the customer and Molde Liftty AS.

Consider the project timeline attached to this case exercise. Follow the steps in order to map the optimal degree and timing of the steel structure supplier involvement in the most recent Molde Lifty AS project. It is assumed that all other suppliers the company might use are not critical, available, and ready for the project.

Exercise 3

Based on the outcome of exercise 2 and in regards to the high degree of involvements, please write at least 3 activities or measures regarding how Molde Lifty AS and the supplier can achieve the identified involvements.