UNIVERSITY OF AGDER

To Increase Predictability in Complex Engineering and Fabrication Projects

Construct of a Framework for Planning and Production Control in FMC Technologies

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This master's thesis is carried out as a part of the education at the University of Agder and is therefore approved as a part of this education. However, this does not imply that the University answers for the methods that are used or the conclusions that are drawn.

University of Agder, 2014
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I. PREFACE

The master's thesis is written as the final report of our M.Sc. degree in Industrial Economics and Technology Management at the University of Agder, the Faculty of Engineering and Science, the Department of Engineering Sciences. The master's thesis accounts for 30 credits, and was conducted during the period from January 2014 to June 2014. Our research case was FMC Technologies in Kongsberg, where we have previously been involved through internships.

Based on the course IND501 – *Supply Chain Management*, the necessity for increased efficiency in complex engineering and fabrication projects seemed an interesting area of research. After contacting FMC, it became clear that there was a need for increased efficiency in the Product Project Manager role. However, our research quickly shifted towards increased predictability in design and engineering processes, which in turn will improve the efficiency of the Product Project Manager. The research area has been very complex and challenging, but also incredibly interesting.

Concurrently with our research in FMC, a research paper (Lia, Ringerike, & Kalsaas, 2014) has been accepted for the 22nd annual conference of the International Group for Lean Construction. Feedback from our supervisors, fellow students and the conference committee has provided invaluable input to our thesis. Also, two other master's theses have investigated similar research topics, which have enabled close collaboration and sharing of experiences.

We would like to thank our supervisors: Professor Dr. Ing. Bo Terje Kalsaas (University of Agder), Technical Training Manager Børge Bjørnaas and PPM Manager Per Kevin Braathen (FMC Technologies). They have all provided us with vital information, ideas and feedback, which has guided us throughout our research. We truly appreciate all the information and guidance provided by our supervisors. In addition, we would like to thank Product Project Manager Merethe Anthonsen and all other employees in FMC that has helped us through interviews and workshops. We would also like to thank AS Nymo for arranging a workshop for us in March.

Kongsberg, 02.06.2014

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II. EXECUTIVE SUMMARY

How to increase predictability in complex engineering and fabrication projects is what it is all about. The case studied, FMC Technologies, is located in Norway, but is part of a global company. FMC has grown quickly, and solving issues with tacit knowledge and personal experience, as was done earlier, is challenging. The unit of analysis within the organization is the department of Well Access Systems (WAS). WAS is concerned with connecting subsea wells to surface rigs or vessels. A typical project consists of complex subsea equipment for work over and intervention of established wells.

The research method is based on a constructive research design for analyzing the case (Lukka, 2003). The constructive research approach is a research procedure for developing constructions that in turn can contribute to the theory connected to the field of research. In addition, constructive research relates to design science research, which according to Simon (1996) is concerned with devising artifacts, e.g. tools, techniques, and methods, to attain goals. Constructive research is a form of prescriptive research aiming at improving the performance of the case being studied. Furthermore, our approach is based on action research (Reason & Bradbury, 2008), as we have been working closely with FMC.

During our exploratory study, we got a comprehensive view of the organization, as well as management processes and tools. Within WAS, two tools are used to plan and follow up on engineering activities. However, the utilization of them does not seem satisfactory to ensure a smooth project execution. The tools are the well-established “Eplan” and the newly developed “PPM tool”. However, we have found that neither Eplan nor PPM tool are planning tools; they are merely progress reporting tools. The PPM tool is based on frequent progress reporting for each task, and Eplan is based on a few milestone dates within each task. The PPM tool was implemented as Eplan does not include all engineering activities, only pure deliverables that are sent to the client. Consequently, Eplan does not capture the actual usage of hours or remaining hours, thus failing to visualize the actual status of projects. Further, the initial planning, which serves as input for both tools, is performed at the startup of the project, usually without sufficient emphasis on the importance of “doing it right the first time”. Thus, inconsistent milestone dates[1] and infeasible resource allocations are frequent. In addition, activities are often planned in parallel with long durations and without dependency links. Consequently, on-time delivery (OTD) of documentation and drawings is found to be low at FMC. In March 2014, the OTD was as low as 38 % on average for all the ongoing projects.

[1] Urgent activities are planned too late, and non-urgent activities are planned too early.

Projects within the subsea oil and gas industry tend to be large-scale, and the financial impact of delays and deviations is significant (Kalsaas, 2013). Thus, increased predictability in the design and engineering phase may reduce the risk of potential outburst from the initial budget. However, due to the nature of the design process, planning serves as a challenging task. Traditionally, several planning strategies used in the design process are based on linear approaches, such as “Stage Gate” and “Waterfall” (Kalsaas, 2013). In addition, complex projects tend to perform concurrent engineering, i.e. a number of engineering activities are underway simultaneously and the entire set of activities converges to the design solution at once (Hoedemaker, Blackburn, & Van Wassenhove, 1999). Yet, traditional planning techniques take little account of the interdisciplinary, iterative nature of the design process (Austin, Baldwin, Waskett, & Li, 1999). Inevitably, this leads to cycles of rework, known as negative iterations (Ballard, 2000b), as well as time and cost penalties in both design and fabrication. Against this background, iterative and inclusive methods for planning design and engineering, such as the Last Planner System (LPS), Critical Chain (CC) and Scrum, must be sought in order to increase predictability and quality of the deliverables. The thesis presents a construct on how the initial planning and subsequent production control can be strengthened by adapting ideas from these methods.

Planning of design processes serves as a challenging task: the design emerges through a complex process where solutions, and thus activities, evolve as the process progress (Ballard, 1999), i.e. reciprocal dependencies (Thompson, 1967/2003). The main idea of the framework, or construct, is to postpone the documentation and drawing phase to the end of the design phase. As such, the design can be fully completed before the production of documents and drawings commences. Further, the two distinct phases can be handled separately, as illustrated in Figure 1. Today, the design and documentation are often conducted concurrently, thus leading to several parallel activities with long durations due to reciprocal dependencies between them. With several designers and engineers working in parallel, this often results in rework, i.e. negative iterations, due to late changes and poor communication. Thus, it is important to freeze the design at some point, in order to make the documentation phase sound.

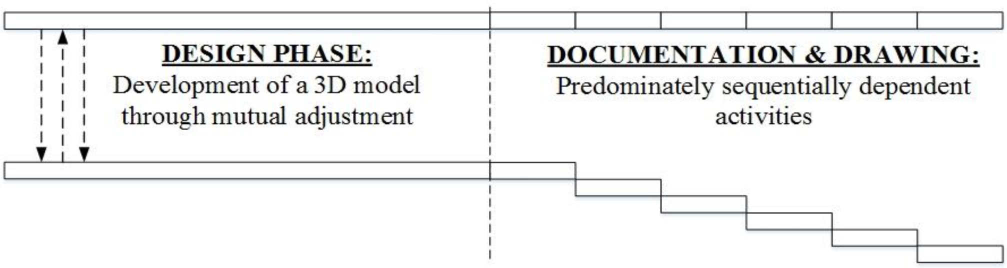

Figure 1: The design phase and the documentation and drawing phase.

The first aspect to consider is the initial planning of the documentation and drawing phase. The main goal of the initial planning is to sequence the engineering activities in the right order to avoid both inconsistent delivery dates and parallel activities with unnecessary long durations. The planning must be executed in accordance with the principles of collaborative planning in LPS, where different disciplines attend to unveil constraints and evaluate the budgeted amount of hours. Based on ideas from CC, resources are allocated in advance to avoid parallel activities on individual resources. Further, the problem of infeasible resource allocations is reduced, while the visibility is increased. The latter removes the necessity of the frequent progress reporting done today, which further renders the PPM tool unnecessary. Today, parallel activities on individual resources must be reported frequently in order to foresee any off-track activities potentially threatening the delivery or to track cost measures, while sequential activities are more visible and easier to track, as illustrated in Figure 2.

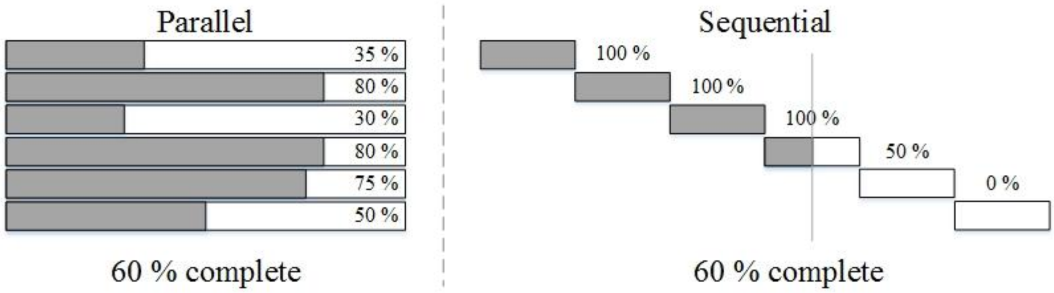

Figure 2: Parallel vs. sequential progress measurement.

By structuring activities according to CC, the problems related to multitasking, Student Syndrome, and Parkinson's Law will be structurally mitigated (Koskela, Stratton, & Koskenvesa, 2010). Herroelen and Leus (2001) point out that multitasking is quite common in multi-project environments where resources often have more than one significant task running. However, such multitasking results in individuals who bounce back and forth, whereas the flow time in individual activities increases. Further, activities stretched over a long period does not motivate the resource to go with full thrust from start, or even begin on the task immediately after the start date, i.e. the Student Syndrome (Leach, 1999). Long durations also affect Parkinson's Law, stating that work expands to fill the time available (Shen & Chua, 2008).

In accordance with CC, buffers are postponed to the end of each activity chain in order to visualize off-track activities. Since several deliverables are subjected to an internal review before delivery to the client, we propose to add buffers at the end of these chains, as illustrated in Figure 3. The size of these buffers must be evaluated collaboratively at the initial planning. No existing method seems satisfactory (Tukel, Rom, & Eksioglu, 2006): however, Shen and Chua (2008) point out that the soundness of the tasks should be of guidance, i.e. the degree of prerequisite work serving as input. Figure 3 illustrates how the logical sequencing of tasks visualizes the upcoming activities for the resource and determines the start date. The blue bars represent the budgeted amount of hours, while the internal review marks the delivery date to client.

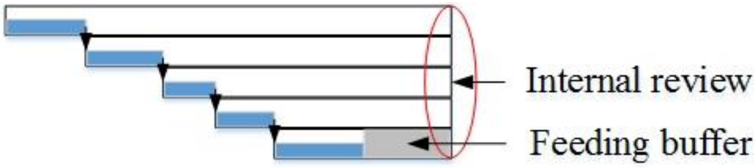

Figure 3: Sequencing of activities with postponed buffer.

For progress measurement, each participating engineer reports progress in accordance with the milestones in Eplan. Further, Eplan updates the Product Plans automatically, which serves as a holistic management tool to control cost, progress, and quality. As suggested by Shen and Chua (2008), the CC framework acts as a linear controlling feature. This is also in accordance with the addressed need of such system in LPS (Junior, Scola, & Conte, 1998; Kalsaas, 2013).

However, as LPS demonstrates, planning and production control[2] are strongly related. Thus, besides the framework for initial planning and progress control, a proper framework securing corrective actions is necessary. The principles of production control from LPS is implemented complimentary to CC, to allow more detailed handling of assignments, flows, and constraints (Shen & Chua, 2008). This is also supported by Koskela et al. (2010), who suggest weekly and daily planning across all tasks, as an extension of CC. We propose weekly forward-looking meetings, where key personnel meet and evaluate upcoming activities spanning six weeks ahead. An important part of this meeting is to make sure that prerequisite inputs are available, or that actions can be taken in advance of the scheduled startup dates, to make tasks ready for execution (Hamzeh, Ballard, & Tommelein, 2008). The most challenging prerequisite in FMC is human resources. Even though the initial planning secures proper resource allocation and workload distribution, the resources might have been reassigned to other projects, or the workload of an ongoing activity might have increased due to variation orders. Thus, it is important to look ahead and see if the upcoming workload is feasible for the resources. Further, it is of interest to evaluate reasons for non-completion of ongoing activities as proposed by Ballard (2000a), in order to improve future planning. Forward-looking meetings are required weekly in order to get frequent updates on ongoing activities, input on the planned workload and commitment to upcoming activities through

[2] Production control is monitoring of performance against project specifications (budget, plans, etc.) and corrective actions needed to conform performance to the specifications (Ballard & Howell, 1998).

public promises, public checking of task status, and evaluation of reasons for non-completion (Koskela et al., 2010). Drawing on the ideas from Scrum, all meeting arenas should be time-boxed and standardized to reduce complexity (Schwaber & Sutherland, 2013). Thus, the meetings should be held at the same time and location, and have a fixed duration and agenda.

Based on the ideas of Scrum and LPS, a framework for planning and production control of the design phase is further described. The Sprints in Scrum are in many ways similar to the phase scheduling in LPS, where activities and their sequence are determined. Handoffs between trades are identified as a part of the process to determine the sequence. The Sprints can be considered as these handoffs, where an increment of the design serves as input for other products' designs. In LPS, the tasks themselves are the central unit of analysis, but Scrum focus on the achievement, or goal, within the phase. This is more suitable when planning future design activities, since it is easier to determine the preferred outcome, than the way of achieving that outcome. In contrast to Scrum, these Sprint Goals must be planned prior to commencement of the design phase. Thus, ensuring fulfillment of the total scope within the planned period, synchronization with other product designs, and providing transparency in terms of progress and cost to project management and the client. A generic set of increments was evaluated for one product. However, it proved impossible to make a generic set of goals because the design is completely project specific, e.g. water depth, field age, installation space, equipment interfaces, etc. Consequently, budgeted hours and percentage of total scope for each Sprint becomes project specific as well. However, our investigation revealed the possibility to either divide into sub-product increments or interface increments[3], depending on the product and project. This must be done as a collaborative process prior to the startup of the design phase. In addition, documentation and specification from systems engineering must be present in order to set the Sprint Goals and ensure soundness of the design phase. In Figure 4, the Sprints are illustrated as sub-milestones within the 3D modelling. Each Sprint's duration should be less than one month to reduce complexity and risk (Schwaber & Sutherland, 2013). These are implemented in the Product Plan for cost and progress measures.

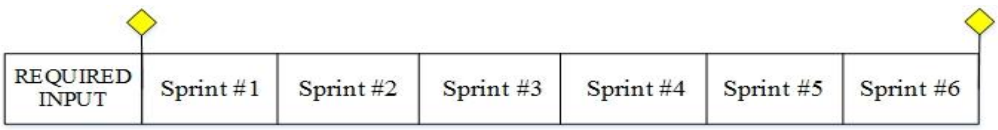

Figure 4: Sprints in the design phase.

The Sprints connected to one product is performed by a Sprint Team, which is self-organizing and multifunctional with the ability to perform all necessary tasks. These are solely

[3] Control areas based on a completed part design, or interface verification between several parts.

responsible for the product design, unlike today where several participants may interfere with the current design. The team collaborates jointly on how the specifications from the client can be implemented in the concept design. However, the team must also collaborate with other teams and representatives from the workshop, suppliers, etc., in order to adjust the design early, and reduce the amount of negative iterations. As Macomber and Howell (2003) pointed out, it is of great importance for the project to use multiple sources to ensure more accurate information. Thus, weekly forward-looking meetings are arranged in the design phase as well. It is important to arrange these meetings weekly, and not only at the startup of each Sprint, in order to secure an arena for frequent mutual adjustment. This is supported by Kalsaas (2013), who claims that the planning period must be shortened, and actions and decisions related to the actual engineering activities must be detailed on a rolling basis with a short-term perspective. The team can invite different disciplines to discuss the current design, thus get a view of any upcoming obstacles, and follow up on these in order to make future tasks sound prior to commencement. An action list, and a design review document (DRM) is used throughout the entire design phase for each product to follow up on hindrances and document the process of the design, i.e. decision points and increment freezes. When the Sprint ends, a retrospective meeting is held in order to freeze the increment and update a register of lessons learned. The learning perspective is important in order to improve future projects and is part of both Scrum and LPS.

The proposed process for the design phase has an additional value for the costumer. Today, if a variation order occurs, it proves difficult to determine the impact on ongoing or completed work. However, if increments are frozen, it is easier to determine the effect on subsequent work and invoice the client accordingly. Also, the DRM serves as guidance to see how the variation order affects previously made decisions, and other products and work packages, thus increasing flexibility. Whenever a retrospective meeting is held, possible extensions in the scope may be proposed, in order to enhance the product beyond the contractual provisions.

In addition to a more comprehensive explanation of the construct presented, an in-depth description of FMC and relevant processes, a better understanding of different types of dependencies and coordination methods suitable to control the dependencies, and a comprehensive evaluation of the framework is provided. The thesis contributes in the broader perspective to the understanding of how increased predictability can be achieved, exemplified by the practical relevance in FMC.

III. TABLE OF CONTENT

1 INTRODUCTION

Complex engineering and fabrication projects within the subsea oil and gas industry tend to be large-scale (Kalsaas, 2013). In addition, the projects are becoming increasingly more complex, with both market competition and increased demand for efficiency, quality, safety and additional specifications from the clients. The financial impact of delays and deviations is significant due to extreme operational costs and potential income losses offshore, thus predictability in the project execution is important to avoid severe time and cost penalties. Although the design and engineering process accounts for a small percentage of the total project cost, it significantly determines the characteristics and eventual outturn cost, both in capital and life cycle terms (Male, Bower, & Aritua, 2007). Consequently, increased predictability in the design and engineering process is important in the total project life cycle to ensure high customer value and on-time delivery. Against this background, continuous improvement in the planning and production control of engineering processes is an increasingly important subject in the industry, as well as the research community.

The case studied, FMC Kongsberg Subsea, is the world's largest supplier of subsea production systems through EPC projects. FMC Kongsberg Subsea had an annual revenue of 10.1 billion NOK in 2012 (proff.no), and approximately 3,600 employees in Norway. Thus, the organization is both extensive and complex. The unit of analysis is the Well Access Systems department, a self-governing division that delivers equipment for subsea tree installation, well completion and intervention activities into system projects. The background for the study is the tremendous growth at the Kongsberg site, making problem-solving based on tacit knowledge and experience challenging. One of the main issues within FMC is insufficient or incorrect planning of design and engineering activities, which results in inconsistent ordering of milestone dates and poor resource allocation. In addition, the progress control fails to capture the actual status of the projects. Consequently, on-time delivery of documentation and drawings is low. Only one third of all deliverables is on time, potentially threatening the final delivery of hardware. Thus, the planning and engineering control in FMC is no longer perceived satisfactory. Against this background, there is a need for increased predictability in the project execution. Thus, we raise the following research question in our thesis:

How to increase predictability in complex engineering and fabrication projects?

In this thesis, we show that planning and engineering control methods must acknowledge the iterative nature of design and engineering activities. Linear models have proven insufficient for planning and engineering control of design processes, thus there is a need to apply key elements from more iterative and inclusive methods. Consequently, ideas from the Last Planner System of Production Control (LPS), Critical Chain Project Management (CC) and Scrum are interesting contributions. Furthermore, we present a construct for planning and engineering control aimed at increasing the predictability of engineering deliverables in FMC. The construct divides the project execution phase into a design phase and a documentation and drawing phase. The design phase utilizes elements from Scrum and LPS. The idea of implementing Scrum alongside LPS comes from the question raised by academia and practitioners of the function of LPS in design. Production of documents and drawings are postponed until completion of a 3D model of the product, thus reducing the amount of negative iterations currently experienced. The documentation and drawing phase utilizes ideas from CC and LPS. As an answer to the need for a holistic cost and progress system in LPS (Junior et al., 1998; Kalsaas, 2013), we implement appropriate elements of CC. Furthermore, it has been verified that the division of the execution phase will significantly ease the design process in FMC.

All the methods used are well known in the research community and have been developed through numerous papers and conferences, especially LPS through the International Group for Lean Construction (IGLC). Our thesis has been summarized and generalized in a paper, which has been accepted in the Proceedings of the 22nd annual conference for the IGLC, and will be presented at the conference set in Oslo, June 2014. Thus, our research also contributes to the development of LPS in design, and will be distributed to a wider research community through the conference.

The method is based on a constructive research design for analyzing the case (Lukka, 2003). The constructive research approach is a research procedure for developing constructions that in turn can contribute to the theory connected to the field of research. Constructive research is a form of prescriptive research aiming at improving the performance of the case being studied by devising artifacts, e.g. tools, techniques, materials, and sources of power, to attain goals. Furthermore, we apply an action research approach (Reason & Bradbury, 2008), as we have been working closely with FMC.

Our research differs from previous studies as we apply methods that primarily have been used in other industries than the EPC industry. For example, there has been extensive research of LPS in construction and Scrum in software development. Yet, no significant research into the combination of the methods, especially in the EPC industry, has been carried out prior to our research. In addition, a need for a holistic management system in LPS has been addressed, where CC has been proposed. However, no extensive research into the parts of CC applicable for LPS has been performed earlier.

The remainder of the thesis is structured as described in Table 1.1.

Table 1.1: Description of content.

Methodology	In the methodology we present our methodological approach, the research design and data collection, and discuss the validity and reliability of our research.
FMC Technologies	This chapter describes the unit of analysis, the project life cycle and processes during the project execution.
Case Description	In this chapter, we look closer into the area of research in which we seek to improve within FMC. Planning and progress control is examined explicitly.
Theories, Methods and Concepts	This is the academically background used to support our construct. The theories, methods and concepts presented are invaluable input to understand how increased predictability can be achieved and why it is sought.
Narrowing the Field of Research	In this chapter, we provide a summary of our findings and discuss what we will construct in order to increase predictability of the project execution.
The Construct	An extensive description of our construct is provided alongside figures, examples and discussions. Finally, we summarize the construct.
Evaluation and Testing	In this chapter we evaluate to what extent our construct mitigates the problems found during our exploratory study, and determine a set of criteria to evaluate the construct.
Conclusion	A conclusion of our research is provided alongside propositions for future research.

2 METHODOLOGY

The purpose of this chapter is to describe and explain the methodological approaches used in the thesis. Through our thesis, we have relied on a combination of approaches, as well as sources of evidence. It is important to understand our approach, perspectives and data collection process in order to appreciate the research presented. Our research is within a critical realist perspective of the world (Ackroyd & Fleetwood, 2004), in which the presented data represent the physical world while our perceptions and explanations are socially constructed, i.e. we are subject to opinions and understandings of others. However, our intention as researchers is to explore links between actions, challenge assumptions and explanations, explore new interpretations of practice, and present them as objectively as possible. The chapter is structured as follows: firstly, we present our research design. Secondly, we describe the research process from start to finish, especially how our area of research has shifted to find the best possible area for improvement within FMC. Thirdly, our sources of evidence and data collection procedure are discussed. Fourthly, we discuss the quality of the research design with emphasis on validity and reliability. Finally, we provide a summary of our research process and the reliability and validity of our research.

2.1 THE RESEARCH DESIGN

The basis of the master's thesis is a theoretically informed case study (Yin, 2009). The case being studied is FMC Technologies and the Product Project Manager (PPM) role within the Well Access Systems division. Case studies are preferred when dealing with questions of "how" and "why", because it allows the researcher to investigate a contemporary phenomenon within its real-life context (Yin, 2009). Although several important elements of case studies derive from Yin (2009), our case applies a constructive research design for analyzing the case. Constructive research is an exploratory research design well suited to explore ill-structured problems (Holmström, Ketokivi, & Hameri, 2009). By ill-structured, we refer to situations were goals or the way of achieving goals are unknown or disagreed upon. In our case, defining the area of research and the way to improve this area was not well defined initially, thus an exploratory research was necessary. The central notion of the constructive research approach is a research procedure for developing constructs that in turn can contribute to the theory connected to the field of research, as well as improving performance of the case being studied (Lukka, 2003): illustrated in Figure 2.1. Constructs refer to entities, i.e. human artifacts such as models, diagrams, plans, organization structures, and communication systems, which produce solutions to explicit problems (Kasanen, Lukka, & Siitonen, 1993) or to attain goals (Simon, 1996). Furthermore, S. T. March and Smith (1995) describe design science[4] as being technology-oriented, where technology includes tools, techniques, materials, and sources of power that humans have developed to achieve their goals. It is clear that technology, constructs and artifacts describe the same phenomenon: tools or techniques created by humans to aid them in achieving their goals.

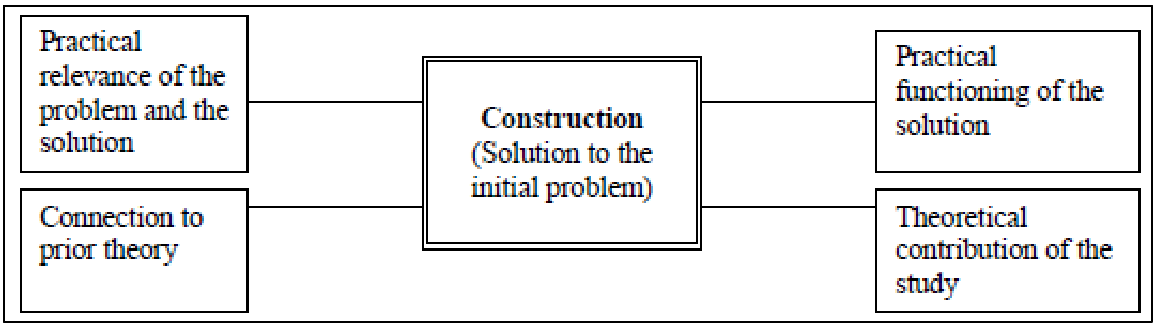

Figure 2.1: The constructive research design (Lukka, 2003, p. 2).

Furthermore, our approach is based on action research (Reason & Bradbury, 2008), as we have been working closely with FMC Technologies. Action research is a participatory, democratic process, which seeks to bring together action and reflection, theory and practice, in the pursuit of a solution to pressing issues (Reason & Bradbury, 2008). Action research is also a form of exploratory research. Interestingly, action research is one way of conducting constructive research as long as the research is explicitly concerned with designing and implementing a means to an end, i.e. a construct (Holmström et al., 2009).

Constructs are a major part of this thesis. Firstly, through our exploratory study we have provided a comprehensive summary of processes and ways of leading within FMC today, as presented in Chapter 3. To obtain all the information provided, we have relied on multiple sources of evidence, and collected and summarized the most important aspects of the organizational structure, project execution, and design and engineering processes currently used in FMC. This information is invaluable for all PPMs, both established and future employees, as the PPM role is complex and difficult to master. Secondly, we have analyzed the planning and progress control methods in more detail, which is presented in Chapter 4. This was analyzed in order to develop a new construct, or “way of thinking”, based on elements of the Last Planner System, Critical Chain Project Management and Scrum. The purpose is to increase predictability in the project execution by restructuring the planning to ease the engineering control, described in detail in Chapter 7.

[4] Design Science and Constructive Research are two names describing the same research approach.

2.2 THE RESEARCH PROCESS

The research process is structured as the framework presented by Lukka (2003) in Figure 2.1. In the first subsection, we describe our research from startup until we found the research area presented in the thesis. This work was time-consuming, but essential to our research. Thus, we present a description of our journey to find a relevant area to implement a practical solution to combat the issues experienced in FMC. Secondly, the connection to prior theory is discussed. Thirdly, the construct, i.e. the solution to the practical problem, is presented in short, as it is discussed in more detail in Chapter 7. Fourthly, a short introduction to the practical functioning of the solution is presented. Finally, we discuss the theoretical contribution of our research.

2.2.1 Practical Relevance

Initially, we had a very broad research area, namely how to increase efficiency of the PPM role. Thus, we conducted an exploratory study of the role by mapping the existing value chain within engineering and fabrication, as well as identifying critical parts of the value chain for further research. As such, the exploratory study served as a basis for obtaining a comprehensive understanding of the organizational structure, project structure and the way of managing projects as a PPM. We examined the PPM's responsibilities during the project life cycle, including scheduling and planning, engineering, purchasing, manufacturing, assembly, testing, and closeout activities. Even though this exploratory study was comprehensive, we have not fully implemented all the findings in our thesis. However, the findings from the initial study not implemented in our thesis are stored in our case database.

Our further work concentrated on finding the best possible area of research. After several discussions and meetings, planning and progress tracking of engineering activities was found to be an important improvement area, especially considering there are two tools for progress tracking within the WAS division. Thus, we finally arrived at the presented research question: "how to increase predictability in complex engineering and fabrication projects?" In order to answer this question, we started out by describing both the tools used for progress tracking by conducting meetings with key informants, who gave us invaluable input. However, a significant issue when describing the tools was the availability of information. There are several work instructions considering Eplan, but the PPM tool was not described in detail anywhere. In addition, the utilization of the tools varies among employees. Thus, understanding and describing the tools was a major task.

Furthermore, we found that the initial planning served as a challenging task due to a low emphasis on “doing it right the first time”. Consequently, inconsistent milestone dates, infeasible resource allocations, long task durations and low on-time delivery were frequent issues. To combat these issues, we examined the initial planning on all levels, from project planning to activity planning. Subsequently, we found that some work had been done in this area: an attempt to plan all the engineering tasks on the EDP and LRP[5], where the main goal was to create a feasible plan with sequential tasks. Yet, the main design activity was still a single task with a duration in excess of six months. There was no sufficient way of tracking progress of this task, except from qualified guesses implemented in the PPM tool. Finally, our attention turned to the design phase and how to plan and track progress efficiently, as well as engineering control of documentation and drawings in the subsequent phase. Interestingly, ways of planning and managing design activities is a pressing issue in research nowadays. For example, the International Group for Lean Construction (IGLC) seeks ways of managing design activities using the Last Planner System. Thus, we have found a research area which is both interesting for FMC and the research community. In addition, there is a change initiative ongoing in FMC concurrently with our research, called “Good to Great”, which our research may contribute to.

2.2.2 Connection to Prior Theory

Alongside the description of FMC and their processes, we have been gathering and analyzing theories and methods used for planning and production control. Because the most complex part of our research is planning and control of design and engineering activities, the academic background presented in Chapter 5 concentrates on theories and methods closely related to design. Thus, the main theories used in the thesis are design and coordination theory. Design theory is essential to understand the nature of engineering activities, which is a highly iterative process aimed at creating a solution to a given technical problem. Coordination theory, especially the contributions from Thompson (1967/2003), highlights the nature of different types of dependencies and coordination methods used to manage these. As engineering activities tend to be reciprocally dependent to other activities, coordination by mutual adjustment is especially interesting. In addition, the effects of mutual adjustment relate to the Linguistic Action perspective (LAP), thus it was deemed necessary to include this perspective.

[5] Emergency Disconnect Package and Lower Riser Package.

Three different methods for planning and production control are described in detail in Chapter 5, namely the Last Planner System (LPS) for Production Control, Critical Chain Project Management (CC) and Scrum. All of these have distinct characteristics, thus we draw on elements from all of them when presenting the situation today and our construct. In addition, these are compared to traditional planning techniques like the Critical Path Method (CPM). We have summarized characteristics from all the methods in a table to ease the process of understanding the similarities and differences for the readers.

Several other theories and methods have been studied, but are not included in our thesis. Firstly, complexity theory seemed interesting when dealing with highly complex projects. Thus, we analyzed the Cynefin framework (Kurtz & Snowden, 2003) from complexity theory. The framework is used primarily to consider the dynamics of situations, decisions, perspectives, conflicts, and changes, in order to come to a consensus for decision-making under uncertainty. However, utilizing the framework is a challenging task and it did not add value to our thesis to pursue this framework further. Secondly, analytical design planning technique (ADePT) (Austin et al., 1999), a tool for utilizing the design structure matrix (DSM) was studied. We have included some information on how to use the DSM, but ADePT has not been included because we have not exemplified usage of the DSM. Finally, set-based design (Sobek, Ward, & Liker, 1999), a method where several concepts are developed in parallel with feedback from downstream actors was analyzed, but not included.

2.2.3 The Construct

Our construct is twofold, i.e. the report and our proposed framework for planning and engineering control are both constructs. The report includes a comprehensive description of FMC’s project life cycle, the planning hierarchy and tools used for planning and progress tracking. Until now, there has not been a single source of information, which presents this in a structured and easily understandable way. Thus, we provide examples and figures in order to ease the process of entering into the PPM role. This will significantly simplify the PPM role, especially for new employees. For that reason alone, the case description is extensive. Also, it is necessary for the reader to understand the case in order to appreciate our construct. Without going in detail, the framework proposes new ways of conducting the initial planning to combat issues related to the low on-time delivery of engineering deliverables. We divided the project execution into two separate phases, and describe how planning and engineering control shall be performed in order to increase predictability and quality of the deliverables.

2.2.4 Practical Functioning of the Solution

Due to the fact that we are not able to test our solution, we have to evaluate the solution through a critical discussion in terms of a set of criteria (S. T. March & Smith, 1995). These criteria are considered in detail in Section 8.2. However, the construct is important for FMC, because improved predictability will increase the likelihood of successful project execution, which in turn will increase customer satisfaction and profit.

2.2.5 Theoretical Contribution of the Study

Our report and the new framework draw on elements from design theory, coordination theory, LPS, CC and Scrum for the most part. Thus, we discuss how our research may contribute to the theoretical background utilized in order to develop our constructs in Section 8.2.8. Especially, how LPS, CC and Scrum, which are methods not theories, can be used in other contexts and industries than their main areas is important. For example, LPS is mostly used in construction, while Scrum is used in software development.

Alongside the thesis, we have been working on a paper to be presented at the 22nd annual conference of the International Group for Lean Construction set for Oslo in June 2014. The paper serves as a summary of our research conducted in FMC, and is a way of distributing our findings into a broader context. Thus, our discussions could contribute to development of topics discussed at future IGLC conferences. The paper is called “Increase Predictability in Complex Engineering and Fabrication Projects” (Lia et al., 2014).

2.3 DATA COLLECTION

The purpose of this section is to describe our methods for data collection. We have relied on multiple sources of evidence to maintain the validity and reliability of the thesis (Yin, 2009). All the data collection methods are of a qualitative nature, which is preferred in case studies when analyzing a phenomenon in depth, or when the researcher has low prior knowledge of the phenomenon/case (Jacobsen, 2005). Qualitative methods are more open and flexible; however, they are more influenced by the collection method than quantitative data collection. Yet, it is easier to gather additional information when needed, compared to quantitative methods. In addition, the basis for constructive research is to create, collect and analyze data (Holmström et al., 2009); thus, a qualitative approach is preferred in our case. However, there are some weaknesses with qualitative methods (Jacobsen, 2005). Firstly, they are resource-intensive as multiple sources of evidence must be checked. Secondly, the acquired information is often complex, i.e. large volumes of information, but poorly structured. Finally, the degree to which we are able to generalize our findings is often reduced due to highly context specific data. Yet, most of the qualitative research methods are concerned with primary data, which enables us to control the data, and discuss it, in order to achieve a high reliability of the material presented.

When utilizing qualitative methods, there is no easy way to separate data collection from analysis because we analyze data as we acquire it, and from the analysis, we may change the future data collection. Jacobsen (2005) describes it as an interactive process, as illustrated in Figure 2.2. Quantitative methods follow the process in a sequential order, but when utilizing a qualitative analysis, the process follows the dashed lines as well for frequent adjustments in all areas.

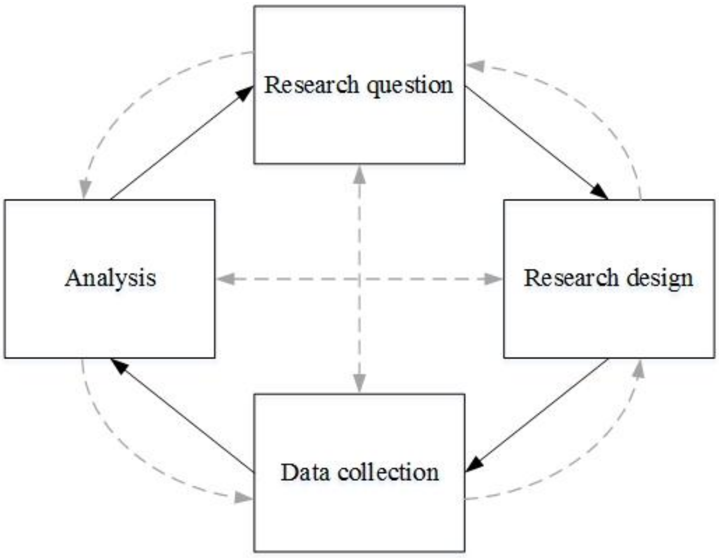

Figure 2.2: The qualitative research process, translated from Jacobsen (2005, p. 116).

In the following subsections, we present our sources of evidence and data collection methods.

2.3.1 Archival Records

Internal documentation at FMC, such as the Business Process Management System (BPMS), Global Project Management and Execution (PME), Project Execution Process (PEP), etc., which are not publicly available have been reviewed. In addition, minutes of meetings, personal notes and checklists, administrative documents (reports, presentations, work instructions, etc.) where obtained and reviewed. Thus, archival records have been a valuable source of evidence in order to describe how FMC execute projects, organize their processes, and the responsibilities of the PPM. However, our inferences from archival records alone are not conclusive, they are mere inferences worthy of further research, i.e. we have used other sources of evidence to support our initial inferences based on archival records.

2.3.2 Informal and Formal Meetings and Discussions

Several informal and formal meetings and discussions with FMC employees have been conducted. In order to get different perspectives regarding the research, we have had individual interviews with different roles within the organization like PPMs, lead engineers, planners (project, product line and material), project engineers, designers, QA engineers, the PPM manager, product line manager, technical training manager, etc. By discussing our research area with employees in different positions, we can analyze the phenomenon from different perspectives in order to bring out nuances. However, we have mainly discussed our research with employees in managerial positions, due to the fact that there is a cost issue linked to work hour consumption. Thus, we believe managers see the long-term benefits of our research, while engineers and designers are more concerned with how to allocate the cost of our interruptions. Even though we believe an objective description of the problems and FMC has been achieved by relying on input from different positions within FMC, our perceptions and explanations may have been subjectively influenced by strong characters or compelling arguments. Yet, by constantly seeking other perspectives and explanations, we still believe there is a strong objectiveness, thus maintaining the reliability of our research.

These interviews have been open: we bring up pressing issues and allow the interviewee to talk freely. Initially, key informants were interviewed to get a comprehensive overview from information-rich employees. Furthermore, the “snowball-effect” has been used, thus asking the interviewee for whom to talk to next. Although some of the meetings and discussions have been informal, we have utilized interview guides to aid us in the process, see Appendix 11.1 and 11.2.

2.3.3 Observation of PPM Meetings

We were present in three monthly meetings for the PPMs. The purpose of observation, in a traditional manner, is to observe (contextual) behavior (Jacobsen, 2005). However, we were not so much interested in behavior, rather observing typical problems, pressing issues and the PPMs responsibilities and ways of leading. Our presence has been known to the PPMs and we have simply been listening and observing the meetings. In addition to the information gathered, our presence has promoted our visibility in the organization. Thus, the PPMs have been welcoming and understanding when we have asked for guidance and information.

2.3.4 Workshops / Group Interviews

Group interviews are appropriate when there is a need to gather several informants to discuss a particular problem or phenomenon (Jacobsen, 2005). We have participated in two group interviews, or workshops. The first was in Grimstad at AS Nymo. At Nymo, we cooperated with two other student groups working on their master’s theses, our academically supervisor and two employees from Nymo: an engineering manager and a quality control system developer. The purpose of the workshop was to highlight different theories and methods appropriate for the master’s theses, and collaborate on possible solutions to the engineering problem, i.e. how to plan and manage complex engineering activities. The groups prepared presentations on Critical Chain, Scrum, set-based design, Design Structure Matrix, and project execution. These presentations, and subsequent discussions, were invaluable in terms of whether or not each theory or method could be applicable to our case.

The second workshop was held at FMC with the group leader for well integrity products (WIP), the technical training manager, a designer and a senior project engineer. The purpose of the workshop was to create a feasible solution for planning and engineering control of the design phase. In advance, we gathered information from designers of how they work, how they obtain specifications and input, how they coordinate their work, etc. Based on this, we had some ideas of how to divide the relatively long design phase into smaller problems, which could be specified in terms of content, input and output. The outcome of the workshop was further implemented in the framework of our thesis, and is documented in a minutes of meeting, which can be found in Appendix 11.3.

2.4 THE QUALITY OF THE RESEARCH DESIGN

The quality of the research design is judged by construct validity, internal validity, external validity, and reliability (Yin, 2009). We divide this section into subsections concerning each of the criteria presented by Yin (2009). Further, we discuss how and why the validity and reliability is strong (or weak) in the context of our research.

2.4.1 Construct Validity

Construct validity is generally used as the vertical correspondence between a construct and its purported measures (Peter, 1981). In other words, are we measuring all of the characteristics of the construct and only those characteristics? Consequently, one particular issue to consider when evaluating construct validity is measurement error, which can be divided into random errors or systematic errors (Bagozzi, Yi, & Phillips, 1991). Systematic error, like method variance, may be experienced through archival biases, key-informant limitations or prejudices, social desirability and halo effects. Archival records is a secondary data source, which may be distorted or falsified (Jacobsen, 2005). In addition, there might be a mismatch between the purpose the data initially was gathered for and what we want to use it for.

However, archival records can be more meticulous or processed, and we have relied on data that is locally or globally accepted in FMC. Thus, archival biases are not a major issue in our case. Key-informant limitations may occur from over- or underreporting of certain phenomena as a function of the informant's position, professional experience, job satisfaction, or other personal or role characteristics. However, all the informants have been welcoming and helpful, and most of them have been employed for several years. Yet, we may have been subject to halo effects[6] of certain strong, compelling characters, but by discussing their arguments and opinions with other informants, a more holistic and correct view of the situations has been obtained.

Both random and systematic errors provide potential threats to the validity of our research, thus it is important to validate and straighten out distortions before testing our inferences and assumptions against theory. Against this background, we have relied on multiple sources of evidence, as discussed in Section 2.3, to maintain the construct validity of the report. By relying on multiple sources, a more holistic and comprehensive comparison of different perspectives and opinions can be achieved. In addition, we rely on triangulation (Guion, Diehl, & McDonald, 2011) to maintain the validity. Multiple sources of evidence is known as data triangulation (Guion et al., 2011). Furthermore, theory triangulation is obtained with the use of multiple perspectives on a single set of data, e.g. using the perspectives of LPS, Scrum and CC to assess our construct. Also, guidance from our academically supervisor, which has in-depth knowledge of LPS, as well as practical experience from engineering and fabrication planning and coordination, helps us maintain the validity. We also use multiple qualitative methods in our research, known as methodological triangulation (Guion et al., 2011). The benefits of triangulation are increased confidence in our research and a clearer understanding of the problems and our solutions.

An essential part of the constructive research approach is to tie the problem and its solution to the accumulated theoretical knowledge. This can be done by demonstrating a chain of evidence, i.e. allowing the reader to follow the research in order to draw his/her own inferences. Thus, there is a logical chain throughout our report, which coincide with our research.

By taking these precautions, we believe the construct validity of the report and the proposed framework is solid.

[6] A cognitive bias in which the overall impression of a person influences how we feel and think about his/her character (Thorndike, 1920). For example, if our overall impression of person A is better than of person B, we would rely more on person A's assumptions and opinions. Typical characteristics: great communication skills, good and accurate feedback, sufficient time, etc.

2.4.2 Internal Validity

By utilizing qualitative methods, the internal validity is often high (Jacobsen, 2005). The reason behind this argument is that qualitative methods bring out the “right” understanding of a phenomenon or situation, due to the fact that there are no strict rules dictating the information received from informants. In other words, if a quantitative method were used we would not bring out nuances and perspectives of certain situations, as we are able to do with the qualitative approach used in our research. In addition, internal validity is concerned with the truthfulness of our results. There are two main measures to assess the internal validity (Jacobsen, 2005): validation by testing against others and validation through a critical discussion.

Validation by testing against others can be achieved by confronting the informants with the research findings. Since we have been working on a paper to the IGLC conference alongside this report, we have been able to distribute updated versions of the paper to informants for review. The paper serves as a summary of the key findings from our research, thus feedback on the paper has been essential for restructuring the thesis in accordance with the informants’ experiences and knowledge of FMC. Furthermore, validation against theory and other relevant research has been performed. Again, triangulation serves as an important measure to ensure internal validity.

Validation through a critical discussion is achieved by reviewing data sources and our analyses. Our sources of data are mainly archival records, key informants and workshops. However, are they representative and do they provide true information? First of all, the archival records are thought to be both representative and true since they are accepted locally and globally in FMC. The representativeness of our key informants may however not be as high as we wanted. FMC is a large organization and it is impossible for us, in the limited time available, to gain access to all the appropriate informants. Yet, we relied on the snowball-effect when interviewing employees to get input on whom to talk to next. By doing so, we always knew whom we should talk to in order to get more information or other opinions. Consequently, our informants are somewhat representative. The truthfulness of their information can be assessed by analyzing their closeness to the phenomenon being studied. All the informants are familiar with the planning and progress control tools and techniques in FMC. However, some are more familiar with Eplan than the PPM tool. Thus, we always asked our informants on their opinion of both tools in order to establish an idea of how familiar they were with the phenomenon we were discussing. When discussing the design process, we mainly talked to designers and project engineers, which have in-depth knowledge and experience with the process. Thus, we believe the truthfulness is high. Consequently, the internal validity of our constructs is thought to be good.

2.4.3 External Validity

External validity is concerned with the generalizability of our research (Jacobsen, 2005). Thus, questions regarding external validity share a common need: to infer the extent to which the effects hold over variations in persons, settings, treatments, or outcomes. In our case, we seek to generalize the findings to a theoretical contribution.

The informants reported that customer demands regarding delivery time and quality is increasing within the subsea oil and gas industry. Thus, it is likely that planning and engineering control is challenging in other companies as well. However, our research may be context specific to FMC and their problems. Thus, we draw on theory and relevant research in order to generalize our findings.

The iterative, incremental design process is well known, and linear approaches have proven their weaknesses in both planning and control of iterative processes. Furthermore, there has been a need to develop LPS in design. Thus, our construct contribute to the predictability of the design process by dividing it into Sprints and freezing increments in order to reduce negative iterations. Using ideas from Scrum outside of the IT industry is both interesting and innovative. Developing 3D models and software has many similarities, and the designers verified that this was an interesting approach, which would significantly ease the design process. In addition, there has been a need to add a holistic management tool in LPS. Consequently, implementing ideas from CC will provide more visibility and predictability in the documentation and drawing phase. Furthermore, by postponing the documentation and drawing phase until a complete 3D model is present, the soundness of the documents and drawings is significantly improved compared to the current situation. Although, the idea of combining CC and LPS is not completely new, we provide useful insights into the parts of CC that are applicable to LPS. We assume that the external validity is good enough to generalize and apply our findings to other EPC companies of similar complexity, at least to a certain degree. Yet, the construct is adjusted to fit FMC, and we believe adjustments must be made in order to use the construct effectively in other companies.

2.4.4 Reliability

By demonstrating that the operations of study (e.g. data collection) can be repeated with the same results, a high degree of reliability can be maintained (Yin, 2009). In other words, our data should not be affected by the data collection methods we have relied on. There are two main categories to consider, namely the data collection methods' effect on the results, and sloppiness (Jacobsen, 2005).

The data collection methods are of a qualitative nature, and to obtain the exact same results is unlikely. There are several reasons for this argument. Firstly, FMC is a large organization, and whom the researchers would get in contact with would probably vary to a certain degree. Other researchers could possibly find other research areas, obtain different input, and interview other informants. Secondly, both the authors have been employed at FMC during internships, thus we have some prior knowledge to the company culture, processes and improvement areas. We are also acquainted with several employees within FMC; however, they have not been included in the research process in order to maintain the validity of the research. Yet, we believe the same results would be obtained if the researchers were given a well-structured research question, like the one we finally arrived at or similarly: "how to increase predictability in the design process?" In addition, the research is context specific, i.e. we have built a construct to suit FMC. Thus, if the research is conducted within another enterprise, the results will probably be somewhat different, although we expect to see similar approaches to what we have used.

Sloppiness in the data collection process and analysis is another way of reducing the reliability. Consequently, we have taken notes diligently in both informal and formal settings and stored them in our case database. Any ambiguities that have arisen have been addressed to informants to straighten out possible distortions.

We assume the reliability to be such that similar research will produce approximately equal results, at least to a certain degree. However, the research is context specific and differences in improvement areas, inferences and constructs are likely to be found.

2.5 SUMMARY

We have used a constructive research approach in order to build a construct that suits FMC. The problem was found to be interesting for both FMC and the research community, thus we performed a comprehensive literature review into relevant theories and methods for planning and production control of design and engineering processes. The construct seeks to improve predictability in the project execution phase, by dividing the design phase into appropriate sub-problems and postponing the production phase until the 3D model is completed. Thus, we reduce the amount of negative iterations, improve predictability and ensure feasible plans. The construct is evaluated in Chapter 8, and we believe the critical discussion proves the practical functioning of it. The theoretical contributions are discussed in Section 8.2.8, and we seek to generalize our findings to other industries. Especially the contribution to the IGLC conference provides the theoretical contribution necessary in constructive research. The research process is summarized in Figure 2.3, where the boxes are weighted in terms of their significance in the research.

Figure 2.3: Constructive research approach adapted to our case. The boxes are weighted in terms of significance.

The validity of our research is thought to be solid. We have relied heavily on data, theory and methodological triangulation in order to maintain the validity. The reliability is thought to be such that our findings can be generalized to other contexts and industries, at least to a certain degree. However, some of our research is highly context specific, and adjustments are needed in order to implement the construct other places than FMC. Yet, ideas and contributions from our construct are both interesting and innovative.

3 FMC TECHNOLOGIES

FMC Technologies Inc. has its roots back to the 1880s by the launch of an innovative spray pump for the agriculture market (fmctechnologies.com). John Bean, the inventor of the pump, introduced Food Machinery Corporation (FMC) and by the 1930s, FMC was the world's largest manufacturer of equipment for handling fruits, vegetables, fish and meat. The company has since derived into various business areas: Subsea Systems, FoodTech, Airport Systems, Defense Systems, Chemical, Fiber and Film. These business areas have become different independent companies, where FMC Technologies is the former machinery business, with roots back to the development of underwater wellhead equipment for offshore drilling in the 1960s. Today, FMC Technologies include various product and service areas, such as subsea systems, fluid control, loading systems, surface wellheads, and remote operated vehicles (Shilling Robotics). The major manufacturing and development sites, customer support centers (aftermarket) and project sites (installation) are illustrated in Figure 3.1.

Figure 3.1: FMC Technologies' global sites (retrieved from internal document).

In 1993, FMC purchased Kongsberg Offshore, the former oil division of Kongsberg Våpenfabrikk, thus becoming the world's largest subsea engineering, procurement and construction (EPC) company. FMC Kongsberg Subsea had an annual revenue of 10.1 billion NOK in 2012 (proff.no), and approximately 3,600 employees in Norway. The thesis is centered on the Kongsberg office, the head office for the Eastern Region of FMC Technologies, hereby referred to as FMC. The Kongsberg site contains a workshop, a technology lab, and product and project engineering environments with its supporting departments, see Figure 3.2.

Figure 3.2: FMC Technologies, Kongsberg site.

3.1 THE UNIT OF ANALYSIS

The division studied is the Well Access Systems (WAS), which delivers equipment for subsea tree installation, well completion and intervention activities. The department is self-govern and delivers products from the product line into system projects in accordance with the project's Scope of Supply (SoS). The product line consists of emergency disconnect packages, lower riser packages, surface flow trees, circulation heads, riser systems, control systems, and more. Within the division, there are several forms of projects, such as development projects, studies, aftermarket projects or workover projects, and standard delivery projects. Further, we will only look into standard delivery projects, i.e. EPC projects. An EPC project includes engineering, procurement, manufacturing and test activities. The way an EPC project is organized might differ depending on whether the project is part of a portfolio or standalone. However, we will base our thesis on a regular standalone process.

The background for the study is the tremendous growth of the Kongsberg site, making problem-solving based on tacit knowledge and experience challenging. The site grew by 1,650 employees over the last two years, making a total of 2,200 employees. In the project organization, the PPM has a central role, and hence plays a vital part in the company.

The PPM is the link between the project manager and the product lead engineer. The lead engineer is responsible for technical issues regarding the product and is supported by the project engineering manager, which has the overall technical responsibility. The PPM must report progress related to cost to the project administration, managed by the system project manager (PM). The project administration also includes links to the project quality manager, HSE manager, contract engineer, cost controller, planner, logistics planner, risk manager and project administrator, see Figure 3.3. Thus, the PPM role includes massive coordination throughout the project.

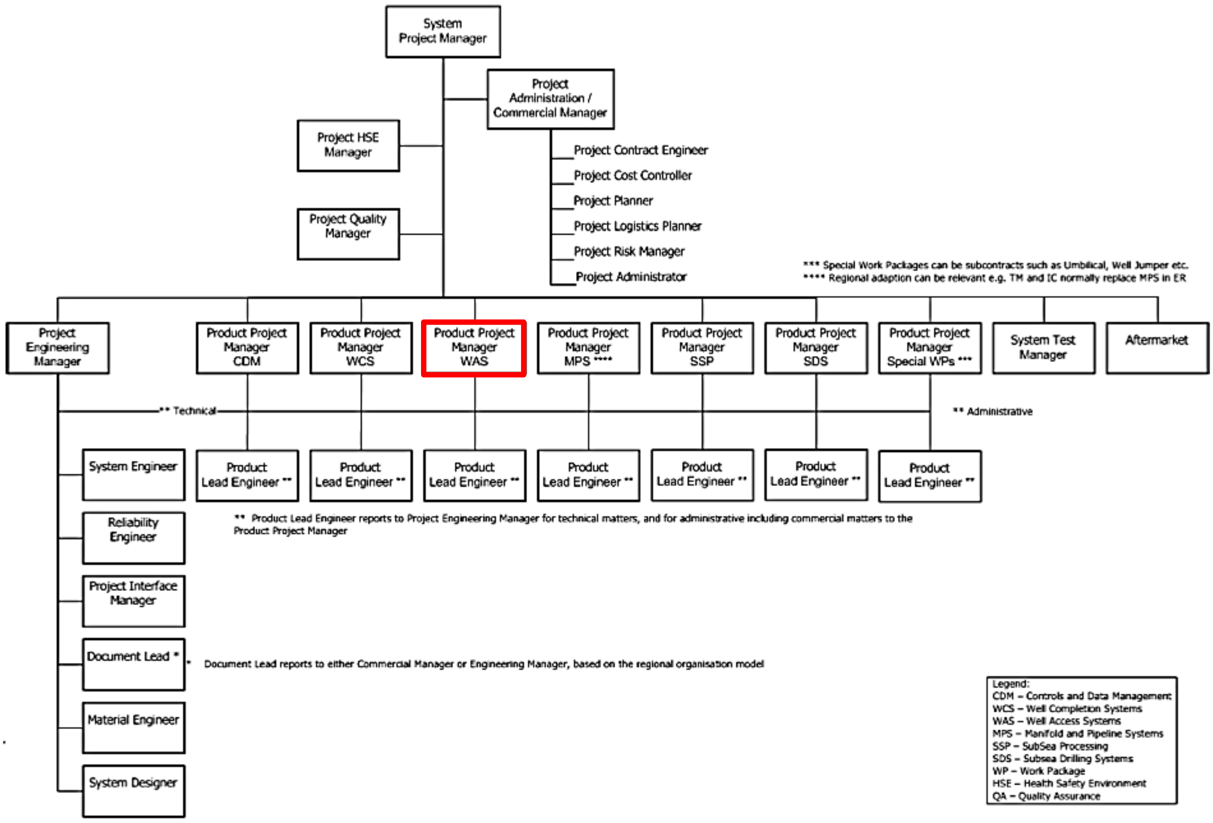

Figure 3.3: Standard organization chart for EPC projects.

3.2 PROJECT STRUCTURE

To understand the role of the PPM in more detail, it is necessary to introduce the project structure at FMC. This section will explain the overall project structure at FMC, as well as describing different terms related to the structure and execution. The project structure is global and thus standardized at all FMC departments. The section is structured as follows: first, the work breakdown structure is explained. Second, the project life cycle model and the Stage Gate model is presented to understand how projects are executed in FMC. Third, the design review process is examined, followed by a short explanation of the process from engineering to delivery.

3.2.1 Work Breakdown Structure

The Work Breakdown Structure (WBS) is a decomposition of the work to be executed by the project team, thus the WBS organizes and defines the total scope of the project, as illustrated in Figure 3.4. The WBS will help visualizing responsibility, as well as ease the scope for planning and management. The first five levels of the WBS is the project Bill of Materials (BoM), which contains all components required for execution of the project, including rental equipment, test equipment, test consumables, Customer Provided Items (CPI), spare parts, equipment to suppliers (FMCCPI), etc. Thus, the project BoM lists everything needed for delivering the SoS. At the highest level, we have the project number that includes information of location, e.g. K = Kongsberg. Next, the project is decomposed into work packages (WP). Each WP is given a specific number, and for the WAS division, WP 25 and 30 are represented. The structure is further decomposed into sub-systems, product types, products to be delivered and different levels of the products, i.e. sub-parts.

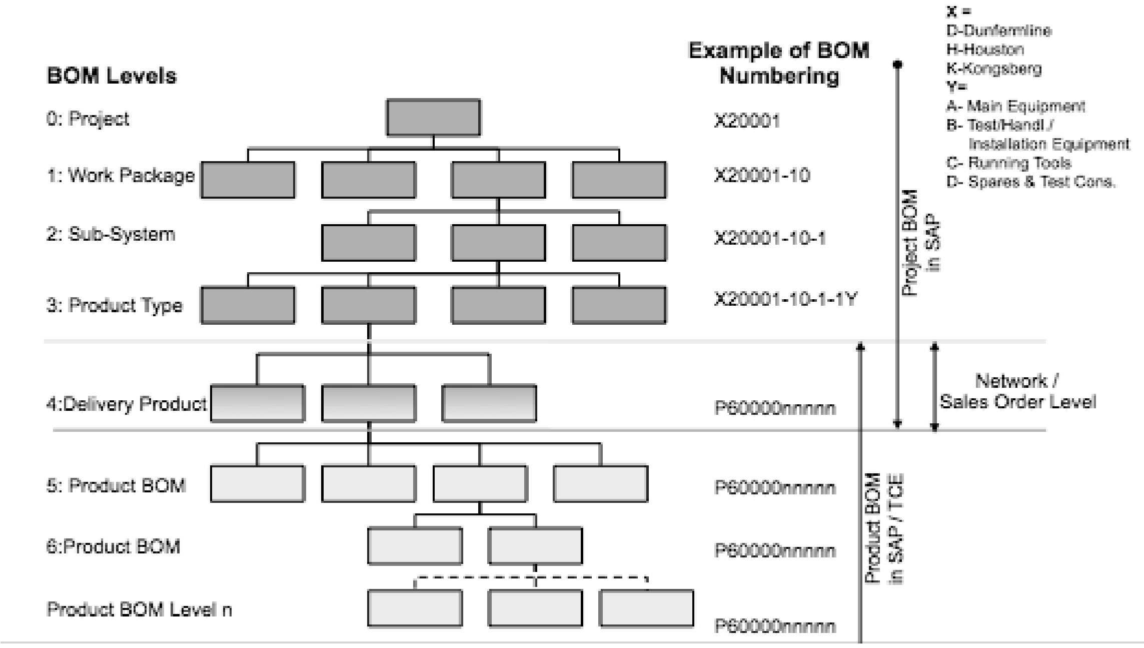

Figure 3.4: Project BOM structure at FMC Technologies.

The product type, level 3, refers to whether it is primary equipment (deliverables), test/handling/installation equipment, running tools, or spares and test consumables. At this level, the products are standardized and used for all subsea projects. The fourth level in the WBS, delivery products, is the planning and control level. Cost and progress are planned and followed up in relation to committed cost. The level is connected to Sales Order (SO), which is a list of all products that are part of the SoS, or need to be purchased as a part of the project. The dates for delivery is given in the project plan, and each WP has a unique SO number. The SO will be the basis for the Material Requirements Planning (MRP). Level 4-n is the product

BoM, the structure of the parts, describing the product and the assembly method for the product. Individual part numbers (PN) refers to each part/material within the product.

3.2.2 Life Cycle Model for Project Execution

To understand the business processes at FMC, the different stages of an EPC project, i.e. the life cycle, is presented in Figure 3.5.

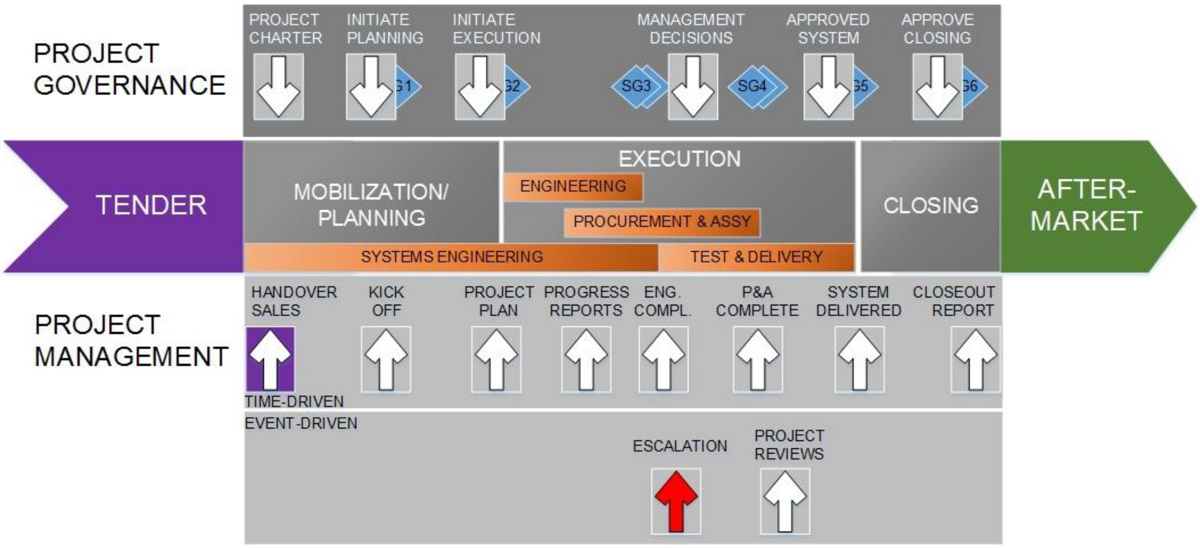

Figure 3.5: Life Cycle Model for project execution.

The PPM is not directly involved in the project until handover from the tender. The final responsibility for the PPM in the project life cycle is the closeout, before handover to aftermarket (customer support). We further concentrate on the mobilization and execution phase of a System Project, where the System Project refers to a subsea project containing all phases of EPC: design/engineering, procurement, manufacturing/assembling and testing.

The System Project can be further decomposed into FMC's Stage Gate model, as shown in Figure 3.6. The Stage Gate model is implemented to ensure on-time delivery (OTD) during all stages of the project execution. This is important for reaching overall project delivery dates, but also because FMC invoice the customer according to progress. Each stage will represent a milestone to ensure that project requirements and designs are according to Baseline, i.e. dates specified in the project schedule. The stages range from zero to six.

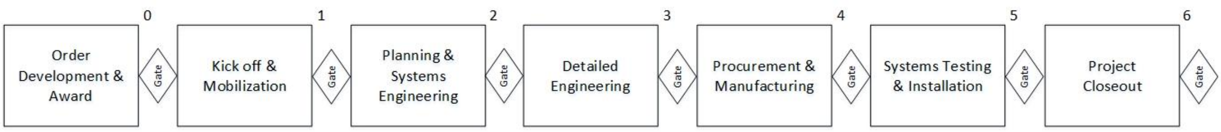

Figure 3.6: Stage Gate model for project execution.

3.2.2.1 Stage 0: Handover from Tender

After handover from Tender, the engineering manager must develop the master equipment list (MEL) with assistance from lead engineers and PPMs. The initial sourcing plan for Long Lead Items (LLI) is also a part of this stage. At this stage, the PPM is responsible for creating a project sourcing plan with input from planning, engineering and the overall supply chain. The plan includes an impact analysis of the project with regards to the supply chain, capacity for sourcing standard items, a strategy on managing items that have pierce lead-time, and a strategy for sourcing non-standard items, including the qualification of new supply chains.

3.2.2.2 Stage 1: Kickoff and Mobilization

The first stage in the project value chain includes the mobilization, a 60-day schedule, and startup of the project. The stage involves project kickoff, establishment of project tools, contract review, startup of activities (e.g. purchase LLI), lessons learned review, update of MEL, etc. This is important to ensure a common understanding of the SoS/project, as well as building upon a common framework. The sourcing plan created during Stage 0 ensures that qualified vendors have been identified for all standard and high-risk parts, and that any deficiencies are noted and appropriate actions are in place to mitigate risks.

3.2.2.3 Stage 2: Planning and Systems Engineering

During Stage 2, the goal is to create the initial project plan, schedules and budgets in order to enable monitoring of the project in later phases. This also includes the engineering plan (Eplan) with the Master Document Register (MDR), manufacturing plan and test plan. The engineering plan describes the process used by FMC to manage the engineering associated with design, manufacturing, assembly, test and installation, and management of spares. The engineering plan will apply to work that is performed at FMC and at FMC’s subcontractors. The manufacturing and test plan includes locations and management of activities. The PPM is responsible for conducting a review and updating the manufacturing plan, as well as the sourcing plan and MEL. The plans are often revisited and updated during the project execution.

3.2.2.4 Stage 3: Detail Engineering

In addition to updating relevant lists, plans and budgets, an important aspect of Stage 3 is to freeze product designs. The most interesting and challenging part of the stage is the design review process, which is described in Section 3.2.3.

3.2.2.5 Stage 4: Procurement and Manufacturing

The procurement process will differ depending on the part or item to be purchased. FMC practices both decentralized procurement within different discipline areas, and project specific procurement. Standardized products are decentralized in teams for better understanding and utilization of the global sourcing market, supplier development, project-product-process synergy and economics of scale. Upon receipt of procured items, the manufacturing or assembling of products commences. According to the Stage Gate process, a HAZOP/HAZID analysis for the final installation will be conducted to unveil concerns regarding the interface between FMC's equipment and the customer's offshore construction and operation vessels.

3.2.2.6 Stage 5: Systems Testing and Installation

After the procurement process there will be various test sequences, both on the part level and on the sub-system or product level. This will depend upon the equipment and its functionality. Any deviation with expected test results will lead to investigation and actions to mitigate the problem. The system test includes: System Integration Test (SIT), Stack-Up Test (SUT), Shallow Water Test (SWT), Cool Down Test (CDT) and Extended Factory Acceptance Test (EFAT). After successful testing, the products will be delivered according to contract, schedule and approved variations. Delivery meetings are held to ensure delivery according to Master Shipping List (MSL).

3.2.2.7 Stage 6: Closeout

Closeout is the final stage before handover to customer support. A register for lessons learned will be finalized to secure future improvement. However, a review of lessons learned will be held throughout the project, both internally and with the client. After updating the lessons learned register, the milestone dates, and codes in the delivery schedule, the WP can be closed. A closeout report is made, and the PPM contributes to this report. Finally, a handover to customer support is conducted as a basis for the aftermarket support to the client. The handover package to aftermarket will be the responsibility of the project manager, and includes product warranty start and finish dates, bank guarantees, acceptance of delivery document from the client, verification of closed project WBS, user documentation, and engineering documentation.

The Stage Gate model will add up to the "V" in Figure 3.7, from initiating the project to the project closeout.

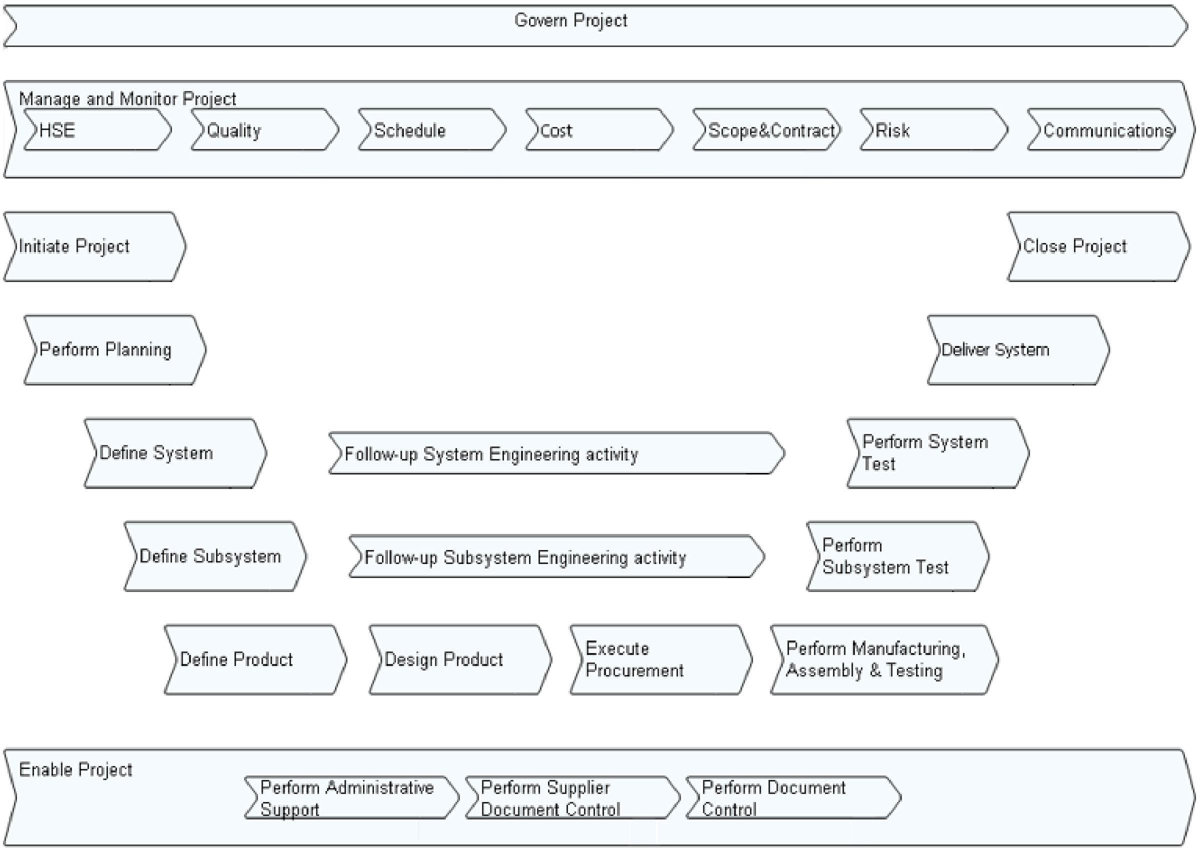

Figure 3.7: Business Project Management System (BPMS).

The model in Figure 3.7 serves as guidance to ensure sufficient execution of the project's phases. Yet, there will be a need for constant management and monitoring of the project with regard to HSE, quality, schedule, cost, scope and contract, risk, communications, personal development, customer value, etc. As the model illustrates, there will also be a need for following up on both system and sub-system engineering activities.

3.2.3 Design Review Process

Engineering activities will be performed during several stages of the project execution. The purpose of the design reviews is to ensure a robust design that has been thoroughly reviewed and documented. The design review process ensures adequate senior engineering and multi-functional participation, and a design that can be procured, manufactured, inspected, tested, installed, operated and maintained in an efficient, cost-effective and timely manner. The process is described in the Global Work Instruction (GWI023, 2011).

There are four levels of the design review process (DR-1 to DR-4), each of whom will freeze the design in order to allow the next level of the process to commence and to avoid unnecessary iterations. The overall design process is illustrated in Figure 3.8.

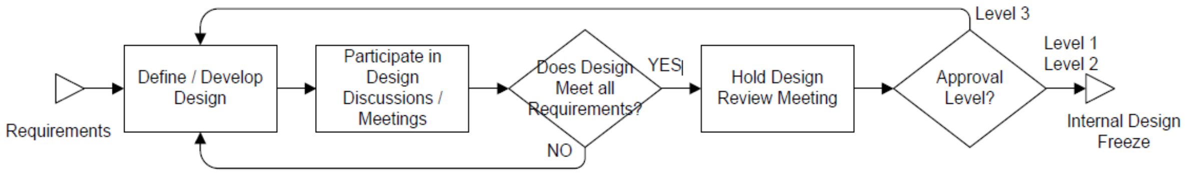

Figure 3.8: The design definition, review and approval process (GWI023, 2011).

Based on specifications from the contract, tender etc., the appropriate designs are defined and developed. After a design meeting, the design is evaluated against predefined requirements. Rejected designs are further developed before a new design meeting may commence. Approved designs are investigated through a design review meeting and assigned an approval level. Level 1 and 2 are approved designs. However, level 2 designs are incorporated with comments. Level 3 designs are rejected. Design meetings are both informal and formal dialogue with various personnel throughout the design of a system, while a design review meeting is a formal and documented conclusion and approval of the design. The approval freezes the design for any portions of the design that are approved. Thus, several design review meetings may be necessary to fully approve and freeze all portions of the design.

System Design Review (DR-1) must take place on all EPC projects to ensure that sufficient and accurate system data are defined to allow sub-system design to commence, and to plan the subsequent design process. Sub-system Design Review (DR-2) must take place in order to ensure sufficient and accurate sub-system data. The DR-2 concerns technical solutions with defined interfaces to other sub-systems, external interfaces, as well as meeting the cost ceiling, enabling reuse of standard solutions, etc. Both DR-1 and DR-2 are part of Stage 1 in the Stage Gate model, thus conducted during the mobilization phase.

An approved DR-2 allows concept engineering to commence, taking into consideration procurement, manufacturing, testing and maintenance. In this phase, several different concept designs, which meet the required functionality, should be developed and reviewed through design meetings. The final concept must be presented for approval at a design review meeting, DR-3C. Next, Product Design Reviews (DR-3P) must take place to ensure sufficient and accurate data to allow commencement of detail engineering and design. For the DR-3P, due consideration for interfaces, materials of construction, manufacturing, installation, retrieval and maintenance methods, design calculations and cost estimates must be verified and approved by the DR-3P participants. The final review process is the Product Release Design Review (DR-4). In the DR-4 meeting, the detail design of the product must be examined to ensure that product functionality is according to the DR-3 requirements, appropriate interfaces are maintained, relevant calculations are incorporated in the design, and that all required documentation is completed and verified. In addition, a DR-4 is used for sub-contractor documentation reviews where an FMC supplier is involved in the product design. Then, a DR-4 meeting will be held to ensure that design requirements are met, and that the documentation prior to commencement of manufacturing is sufficient. This is also the case if the part is new to the FMC system. Any changes to the frozen product design must be handled with the Change Order Procedure to analyze the impact on project objectives, i.e. cost, schedule, and quality. DR-3 and DR-4 are a major part of Stage 3 in the Stage Gate model.

3.2.4 From Engineering to Delivery

The overall project life cycle follows the Stage Gate model, however each deliverable follows a process from engineering to delivery to ensure project execution according to plan. First, each SoS item goes through the design review process after the appropriate BoM structure is built. Next, procurement may commence, followed by assembly and test (FAT). Some items are part of larger systems or sub-systems, which are subject to additional tests, e.g. EFAT, SUT or SIT. Finally, the SoS is delivered to the client. Figure 3.9 illustrates the process.

DR-1	DR-2	DR-3	DR-4	Procurement	Assembly	Test	EFAT SUT SIT	Delivery

Figure 3.9: The process from engineering to delivery.

In order for a purchaser to generate a purchase order (PO), the process in Figure 3.10 must be followed. The project planner is responsible for releasing SOs, which will generate a need for the material planner. A 1:1 relationship with the BoM must be verified before releasing the SO. Next, the material planner must code a requisition according to how the project wants to purchase the item, e.g. items for production at FMC (E) or procurement of single parts from suppliers (F). When a requisition is released, the PPM is responsible for evaluating the requisition in regards to the work package budget, and releasing the requisition if it is within the budget value. Thus, the purchaser may bid out to potential suppliers and after a bid clarification, the purchaser may establish a PO.

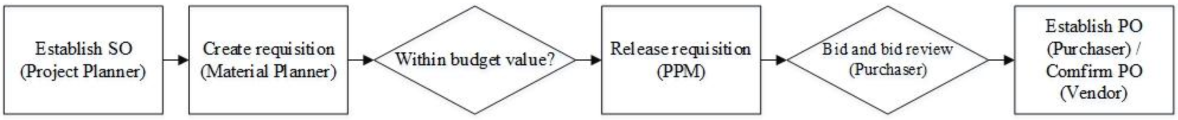

Figure 3.10: The process from sales order to purchase order. Responsible persons are in brackets.

In order for the purchaser to establish the PO in due time to ensure on-time delivery of the SoS, completion of the engineering activities prior to the PO date are a key success factor. These activities are known as “before PO” activities. However, some engineering activities are not needed until later in the “engineering to delivery” process, known as “after PO” activities, e.g. test documentation are not needed until commencement of the FAT. In addition, some activities need input from both engineering and tests, e.g. user documentation. In Figure 3.11, different engineering activities are illustrated as Gantt bars to visualize their sequencing.

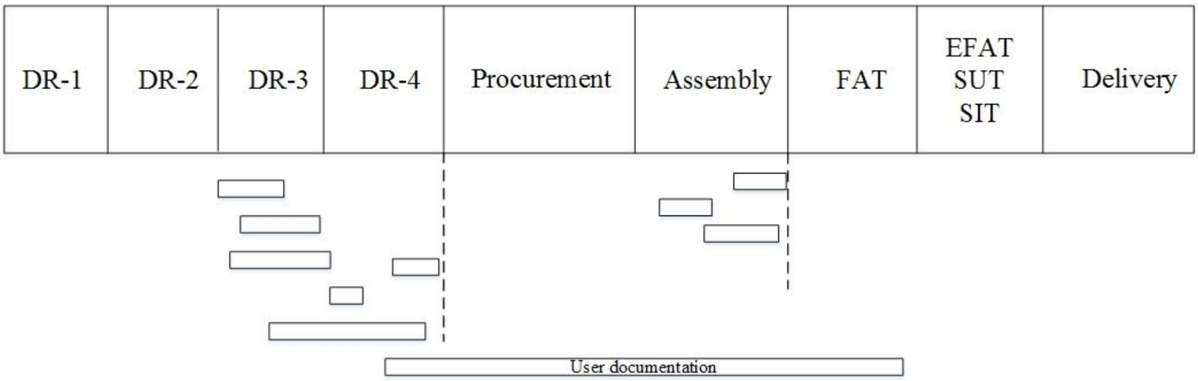

Figure 3.11: From “engineering to delivery” implemented with engineering activities.

The main purpose of this chapter was to provide the reader an understanding of the case enterprise, FMC Kongsberg Subsea, and their way of organizing and executing complex engineering and fabrication projects. The content in this chapter serves a basis for understanding the research areas presented in Chapter 1. The information provided was gathered during an exploratory phase of our research, which was described in Section 2.2.1.

4 CASE DESCRIPTION

During our exploratory study of the organization and the PPM role, planning and control of engineering activities seemed to be a challenging task, affecting several disciplines. To illustrate the problems, we evaluated on-time delivery (OTD) of internal documents, i.e. engineering deliverables, on all projects within the WAS department as of March 2014. The OTD was 38 % on average for all ongoing projects. However, there are differences from project to project, e.g. one project had an OTD of 31 %, while another had 43 %. The validity of the OTD statistic is questionable, due to the quality of the database we investigated. Yet, the OTD reflects what our informants perceive as the current status within FMC, namely that only one third of all engineering deliverables is on time. The OTD distribution is illustrated in Figure 4.1. “NOT OTD” refers to documents with an actual date later than the Baseline date, and “NOT OTD – ToDo & Late” are documents currently not completed, but they are late in regards to the internal Baseline date, thus these are subject to firefighting in order to meet the delivery date to the client.

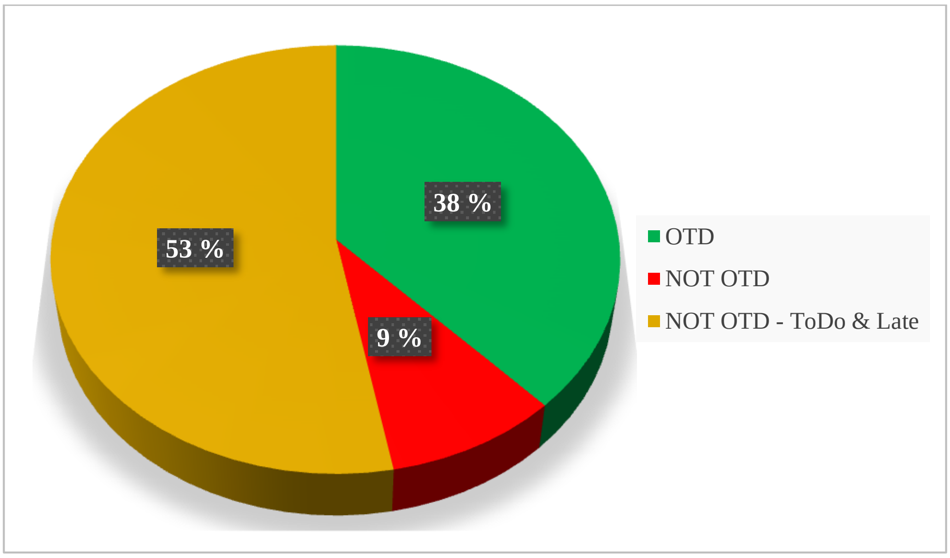

Figure 4.1: On-time delivery (OTD) distribution of all ongoing projects in WAS, March 2014.

Against this background, increased predictability in complex engineering and fabrication projects in FMC became the main research area of our thesis. Consequently, it is of great importance for our thesis to look into the current planning and progress control tools to evaluate their functionality, as well as their application in the organization, i.e. how they are used in order to plan activities and track progress. This chapter seeks to describe the current methods with their strengths and weaknesses, in order to improve current tools, or the usage of the tools. Keep in mind that the chapter is presented prior to the chapter of theories, methods and concepts, even though both chapters have been developed simultaneously.

4.1 PLANNING HIERARCHY

FMC utilizes a planning hierarchy as shown in Figure 4.2. The top level is the Project Plan that summarizes the start and end dates of all major activities for the total project SoS. The detail level is equal to level 4 in the BoM, product for delivery. The Project Plan is governing for the project and shared with the client. In addition, FMC invoice the client in accordance with projected progress. The plan is strategic, known as a “road map”, to manage and guide the overall project execution. Furthermore, it is static, i.e. the Project Plan can only be changed during a Baseline held twice a year. The initial Project Plan is made during the mobilization phase by identifying stakeholder needs and expectations, as well as constraints and interfaces, which are translated into customer requirements. Thus, there is a need to identify critical activities, update the resource plan, and establish sales orders. The Project Plan is very similar to the Master Plan we find in LPS, as it describes main milestones and activities, their sequence and the fact that it serves as guidance for lower level plans. In addition, the initial identification of customer requirements is equal to what we find in Scrum in order to develop a product backlog with prioritized tasks.

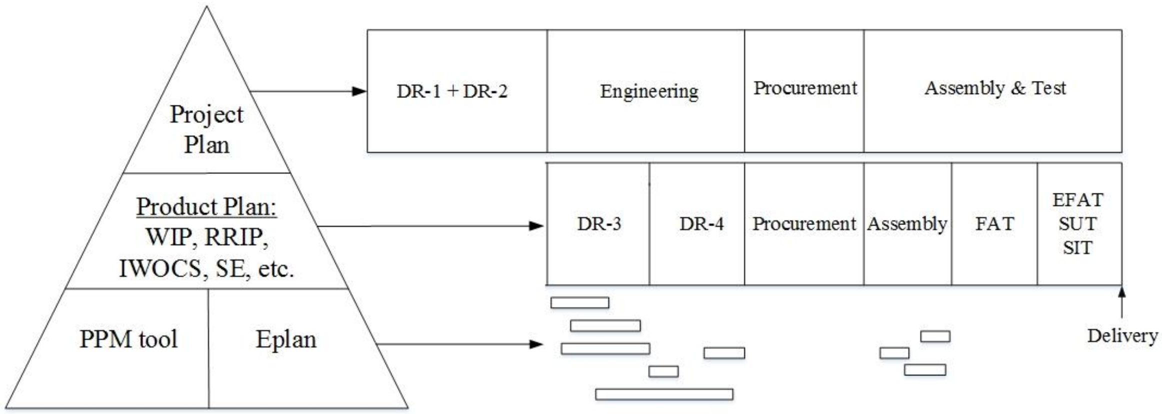

Figure 4.2: Planning hierarchy.

The second level of the hierarchy is the Product Plan, which is based upon critical milestones from the Project Plan, where separate plans are made for each work package (WIP, RRIP, IWOCS, etc.)[7]. This plan is more detailed than the Project Plan, containing milestones for sub-activities prior to delivery. DR-1 and DR-2 are not implemented in the Product Plan as these are held during the mobilization phase as part of the systems engineering. An example of milestone dates for a given set of products/parts from this plan is shown in Figure 4.3. For Long Lead Items (LLI), additional milestones are added. However, we exclude these in our thesis to ease the readers’ understanding of the engineering process.

[7] Well Integrity Products, Riser and Rig Interface Products, and Intervention/Workover Control Systems.

		Milestone dates							
Part number	Description	Engineering start	LLI DR4 release - Raw material drawing to be released	LLI PO (PO is after two weeks)	DR3 release - SPC, GA to be released	DR4 (PO is after four weeks) - Assembly drawing, TST, ASY..to be relased. Preliminary FEA to be finished.	Assembly PO (Start date for the user documents)	FAT (5 weeks before Delivery) (User documents THI, TDI, PSM, OMM, ICP, HFT..should be released & in code 1) The documents should be released atleast 6 to 8 weeks earlier	Delivery
P6000120818	GOOSENECK, DUAL UMBILICAL, ASSY, TH MODE	01.04.14			07.08.14	14.10.14	11.11.14	07.09.15	01.10.15
P6000120817	GOOSENECK, DUAL UMBILICAL, ASSY, XT MODE	01.04.14			07.08.14	14.10.14	11.11.14	07.09.15	01.10.15
P6000120796	STAB POD, ASSY, F/ 7 INCH UN RISER W/ RC Mounting	01.04.14			14.08.14	14.10.14	11.11.14	07.09.15	01.10.15
P6000021615	STABBING GUIDE F/SPEEDLOC, SL215, ASSY	01.12.14			15.01.15	20.02.15	20.03.15	16.09.15	01.10.15

Figure 4.3: Milestones dates for the Product Plan.

Reverse scheduling is used to determine these milestone dates, based upon startup and delivery dates from the Project Plan. Lead-time for the different sequences are used for this matter. Lead-time for the given parts are shown in Figure 4.4. These are based on former experience, supplier information, internal resource information (capacity of the workshop) etc., and represent the feasible window to conduct the needed activities.

Hardware lead time, in months				
Raw material	Machining	Assembly	(FAT) Testing & delivery	Total
0	0	10	0,8	10,8
0	0	10	0,8	10,8
0	0	10	0,8	10,8
0	0	6	0,5	6,5

Figure 4.4: Lead-time for different activities.

The Product Plan is equal to level 5 in the BoM, where all major components needed for the SoS item are shown, as well as sub-assemblies and their sequence in order to assemble the SoS. As such, the Product Plan contains detailed milestone dates for all components/parts. Thus, milestones across several components within an assembly or sub-assembly are synchronized, including overall test sequences requiring several products. Product Plans are required to plan the detailed content of each product release, visualize the consequence of changing priorities and communicate internally.

The Product Plan is a newly implemented plan to increase predictability in the execution phase, thus the use and detail level differ from project to project. However, the Product Plan is created without explicit collaboration across trades. The Product Plan is not static as the Project Plan, as it will be updated during the execution in order to meet the Project Plan milestones.

Both the Project Plan and the Product Plan are made in “Primavera”, which is a planning tool similar to MS Project. However, no detailed information about resources, engineering activities to be performed, or dependencies between these are implemented in the plans, nor are the plans synchronized. To avoid potential impacts on the Project Plan, the FMC Management is keeping the Product Plan separated from the Project Plan. Thus, if one of the Product Plan slip, no significant changes will affect the Project Plan.

The lowest level in the hierarchy is the activity planning level, which for the engineering, plan the detailed activities to be performed. All activities will result in a deliverable, a document or drawing, which is either internal, or submitted to the client or suppliers. At the activity level, there are four main bulks of tasks, as illustrated in Figure 4.5.

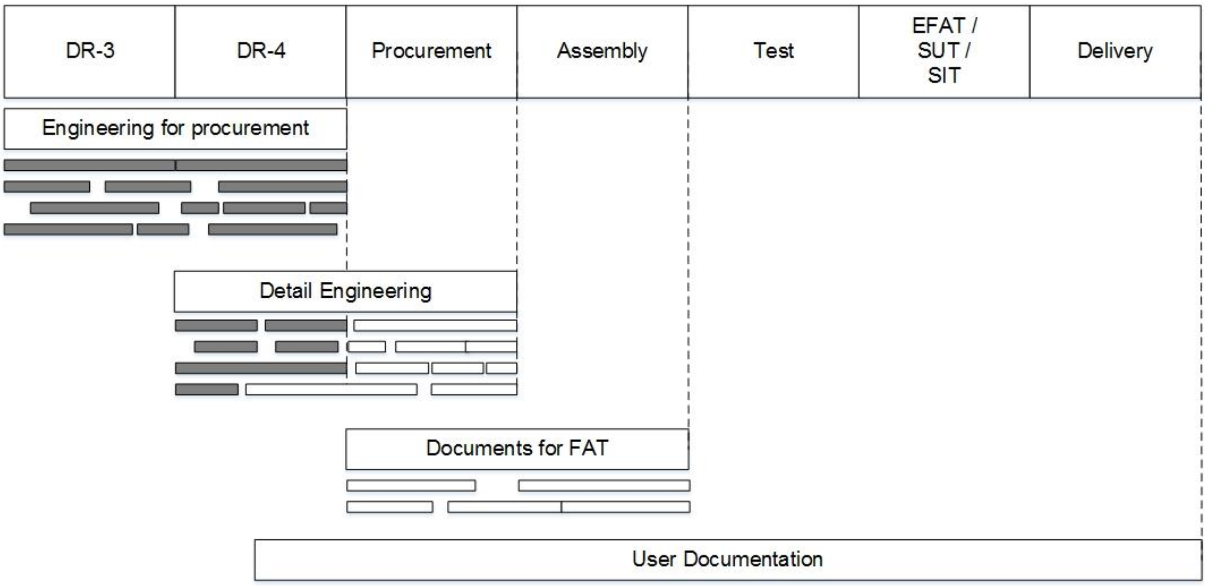

Figure 4.5: Decomposition of engineering activities.

Engineering for procurement includes all documents needed to place a PO. Thus, all these must be completed prior to the PO date, which marks a significant milestone for the product. However, some documents produced in the detail engineering are required as well, shown as grey Gantt bars under “Detail Engineering”. These are equally important to enable a PO to be placed. Further, detail engineering must be completed prior to manufacturing or assembly, while test documents are required before the FAT. Lastly, some documents need input from engineering for procurement, detail engineering, assembly and test results before they can be completed, e.g. user documentation. All the activities shall be planned during the mobilization phase, prior to the first Baseline. This responsibility lies on the WP’s Lead, but is of great importance for the PPM. Unfortunately, little attention to these initial planning sessions has led to poor planning. The practical consequence is threefold:

- Inconsistent order of activities
- Poor resource allocation
- Parallel activities with long durations

Firstly, the activities are frequently found in an incorrect order. Urgent activities are planned with a late startup, resulting in late deliveries, e.g. waiting for input; while non-urgent activities commence earlier than needed, thus occupying resources. As FMC invoice according to progress on predefined engineering activities and milestones, document OTD is of great importance for a project’s success, as well as the company’s reputation.

Secondly, the resource allocation is done with poor emphasizes on the individual resource. In some cases, this has led to an assigned workload of more than 24 hours a day per person in a relatively short period. Thus, it is of interest to avoid potential build-ups of work on specific persons and teams by allocating resources in advance with appropriate workloads.

In addition to the problems of planning in the right order and proper allocation of resources, the duration of the activities are often adverse. Today, several activities are planned with equal start and finish date, resulting in long durations and several activities in parallel on individual resources, as illustrated in Figure 4.6.

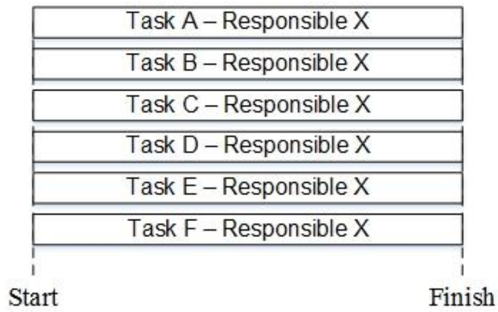

Figure 4.6: Planning as done today: long durations and parallel tasks on the same resource.

Solving the problems related to inconsistent order of activities and poor resource allocation might prove easy with more emphasis on the initial planning. However, the problem of parallel activities is more complex and requires new ideas in the initial planning and subsequent progress control.

4.2 PROGRESS CONTROL

In complex projects, it is required to monitor progress in accordance with milestones and predefined deliverables, such as documents, in order to report to the client. The overall progress of the project is monitored with the use of progress curves, or S-curves, which visualize actual progress in relation to planned progress, measured in terms of hours. If we look at the supply chain of one item in the SoS, we can distinguish between engineering hours (E-hours) and delivery team hours (M-hours). The E-hours are mainly used before a PO is placed, but some engineering is done in parallel with the procurement process, e.g. detail engineering, user documentation, test procedures, etc. On the other hand, the M-hours are mainly used from the PO is placed until delivery to company, but some activities are performed in parallel with the engineering for procurement.

Each PPM reports current work done in his/her WP, as well as any concerns of off-track activities. The total progress is reported to the project management and client on a weekly basis, and an impact on the project schedule is evaluated if necessary. Reporting is done by the simple Percent Progress Complete (PPC) system, which is calculated based on input from actual progress, or earned value of work, measured in hours. Cost is an important aspect in order to report actual performance of the project. From the tender, the PPM gets an estimated amount of hours for engineering and delivery team activities for each SoS within the WP. As the project progress, the PPM must control status on actual performance according to the budgeted value. Cost is measured in used hours, thus the following is measured:

- Earned value of work (progress)
- Actual usage of hours (cost)

To report cost performance, the PPM calculates an estimate at completion (EAC), which is the current estimate of total cost for the activity, measured in hours. The estimate is based on actual usage of hours and remaining hours to completion, as shown in the formula below:

$$EAC = Actual\ usage\ of\ hours + Remaining\ hours\ to\ completion$$

However, the reality is often that the PPM misreads signals on actual progress, and thus reports an EAC that is according to the plan and budget, but not according to earned value of performed work. In addition, the budgeted value of hours might be shortened due to improvements and standardization, or extended due to Variation Orders (VO). Thus, the PPM must be able to keep track on real progress and real cost. Consequently, two progress tracking tools for engineering activities are used: Eplan and the PPM tool.

4.2.1 Eplan

Eplan is a database that lists all engineering deliverables. The database includes information of the person to execute the task, the responsible on a higher level, and different milestones related to the work, namely logical chains, as shown in Figure 4.7.

Engineering - Contractor

Event Description	Start Preparation	Doc. Prepared	Design Review/ Check Out complete	Issue to Company	Reply from Company	Final Issue
Documents/Drawings not subject to Company review(E10)	10	70	90			100
Documents/Drawings subject to Company review(E40)	10	60	70	75	85	100

Figure 4.7: Logical chain for engineering activities in Eplan (INS-0000195, 2011).

Eplan milestones are planned using reverse scheduling where the delivery date of the document or part, serves as a key milestone. However, since the initial planning serves as input, the problems revealed in Section 4.1 still apply. Eplan is not a planning tool like Primavera or MS Project; thus, it is not possible to link different activities directly. However, it is possible to include the part number related to the engineering activity, and use a specific WBS-code at the part level. The data in Eplan can be transferred to a MS Project template in order to visualize tasks with dates in relation to different parts, WPs, projects, or resources. However, such use of the tool seems to be lacking. Today, the tool is mainly used to produce to-do lists and late lists for the different engineering deliverables of the project. However, Eplan is necessary as it serves as the common communication platform with the client regarding engineering progress.

The progress is measured in relation to the logical chain, as shown in Figure 4.7. However, in the process from “Prep. Start” to “Prep. Complete” there is a huge gap between the start of engineering and documentation prepared. For example, when an engineer starts preparation of a document, he/she will report 10 % progress on the activity, but no progress is reported until the document is prepared. For an E10 document, this means that the PPM is unable to keep track of the progress until 70 % of the activity is finished. In other words, the PPM will not know that an engineering activity is off track until the engineers are late with their documents relative to the milestone “Doc. Prepared”. Thus, when the PPM fails to follow up on this, it might have an impact on the SoS delivery.

Each milestone achieved is reported directly from the engineer to the Document Controller, who updates the Eplan status. Thus, each deliverable requires an e-mail, or some other form of correspondence, in order to update the status in Eplan. However, the Document Controller secures the quality of the content in Eplan, since several people working in the same tool might reduce its quality. Yet, due to the fact that each update requires direct correspondence, it is insufficient to update the statuses more frequently. This serves as a challenge for the PPM when estimating earned value of work, and calculating EAC. Thus, the PPM gathers information of the progress through status meetings or email correspondence. This way of gathering information will surely add up to numerous meetings and emails. This is also insufficient because it is often hard to look up the right information, and when the information has passed through several people, it might be wrong as well. Consequently, initiatives from the WAS Management are trying to implement a new tool, the PPM tool, as an addition to Eplan to get more frequent status updates.

4.2.2 The PPM Tool

The PPM tool was developed by the WAS group, and is now mandatory to use by all employees within WAS. The reason for implementing the new tool is to cope with the poor OTD, due to difficulties in progress tracking. As initially described, the real progress unveils too late in the execution for some activities. The PPM tool is not a planning tool, i.e. activities are not linked through a coupled network. However, it is a more advanced tool for tracking progress of engineering activities. One person describes it as “an advanced to-do list”. The idea behind the tool is that a more precise progress tracking of all tasks will lead to an increased likelihood of meeting the milestones, even for a plan containing several parallel activities. The tool has some distinct features that will be described in the following sections.

4.2.2.1 Progress Tracking

The tool is directly connected to each participating engineer. To-do lists are created from the tool, making it easier for the engineers to plan their work and report progress. This enables the engineer to update status on his/her assigned tasks more frequently, compared to Eplan. When reporting progress, the tool calculates hours left in relation to the budgeted value. Each participant should then be aware of the remaining hours in relation to hours used, and thus be able to report at an early stage when extra hours, or resources, are needed. The status update is done by flagging activities: when progress on an activity is on track, the participants simply put up a green flag, but as soon as they see that they are unable to deliver on time, they will put up a red flag. It is believed that frequent progress reporting will increase the awareness of each participant, thus increasing the ability of reporting off-track activities in advance. This is in accordance with the theory of Critical Chain where frequent reporting on progress is done in order to provide more visibility, or predictability, for upcoming tasks, as well as commitment to deliver on time. However, since Eplan activities and dates serve as input to the PPM tool, activities are planned in parallel with long durations, as described earlier. Because of the long durations, the remaining hours do not represent the amount of days left. This makes it is hard, or even impossible for the PPM to estimate a new possible delivery date if the project schedule is changed. Thus, the tool is only focused on reporting cost, and the main concern is whether the activity is according to the cost budget or not. The progress tracking, in order to deliver the document on time, is rather the responsibility of each engineer. Yet, the PPM cannot easily predict whether the engineer will make it in time or not, if the engineer do not flag the activity.

Frequent reporting of progress will increase the awareness and commitment, thus making the execution more predictable. However, concerns about the quality of the reporting are mentioned: both regarding the estimates of work complete and the fact that every participant has access to the tool.

Progress reporting is based on the logical chain, as presented in Figure 4.7 earlier. However, extensions are made to the current logical chain in order to standardize progress steps. These are presented in Figure 4.8.

Progress of Deliverables/Document		
Percentage	**PPM Status**	**ePlan Milestone**
0	Not started	Not started
0-79	In process	Eplan status is Prep Start. Estimate "PPM Percentage complete" by using your expertise/knowledge on completed progress in comparison to total scope of work for deliverable.
80	In process	Eplan status is Prep Complete
85	In process	Eplan status is still prep complete. TCE Review complete
89	In process	Eplan status is still prep complete. TCE Approve complete
90	In process	Eplan status is Doc Check Complete ECN Released in TCE
100	Completed	Eplan status is Final Issue

Figure 4.8: Extended logical chain in the PPM tool.

As illustrated, the milestones are based on deliverables that are not subjected to the client for review (E10). We notice the fact that "Prep. Complete" is set to 80 %, not 70 % as in Figure 4.7. This is because several logical chains exist, depending on the nature of the document. If a supplier performs the activity, other predefined logical chains are used. However, the important aspect is that extensions are made to the current logical chains. This secures the execution of tasks within the activity that are not part of Eplan milestones, such as internal reviews. As initially stated, however, the progress control in the PPM tool lacks a quality aspect. The progress from "Prep. Start" to "Prep. Complete" shall be evaluated in accordance with the following guideline:

"Estimates of PPM Percentage Complete must be carried out by using your expertise / knowledge on completed progress in comparison to total scope of work for deliverable".

This is the part that concerns some PPMs. Freire and Alarcón (2002) argue that early design stages are hard to evaluate in regards to the progress completed and work remaining, due to the fact that there are no deliverables, such as drawings, in the early stages. In production, the progress is reflected by the physical completion from start, and thus easier to estimate. This is also supported by some employees in FMC, who argue that the estimates of work prior to completion is hard to predict, and thus is insufficient for project progress tracking. However, there is no doubt that the awareness of the status is increased for each participant, as well as the commitment for performing the task. Thus, it is more important that potential variations are recognized and handled, rather than a project status that is 100 % correct at all times.

When it comes to the quality of the information, due to the fact that each participant has access to the tool, some adjustments might be necessary. The tool is shared on the intranet, and anyone can change the dates and inputs in the sheet without any quality control. It is, however, necessary to choose a “change mode” in order for the changes to be adapted.

4.2.2.2 Visibility, Information and Communication

A potential advantage of the PPM tool, compared to how Eplan is used today, is that different activities are linked to different part numbers in the BoM. Thus, it should be easier to plan the activities in the correct sequence in order to deal with the problems of insufficient prioritization. In addition, each participant should be able to see the impact of his/her progress in relation to the part, and thus other participants. This will increase the commitment by visualizing the impact on other participants in a rather complex organization. A view from the PPM tool is shown in Figure 4.9, where one part with associated documents are shown.

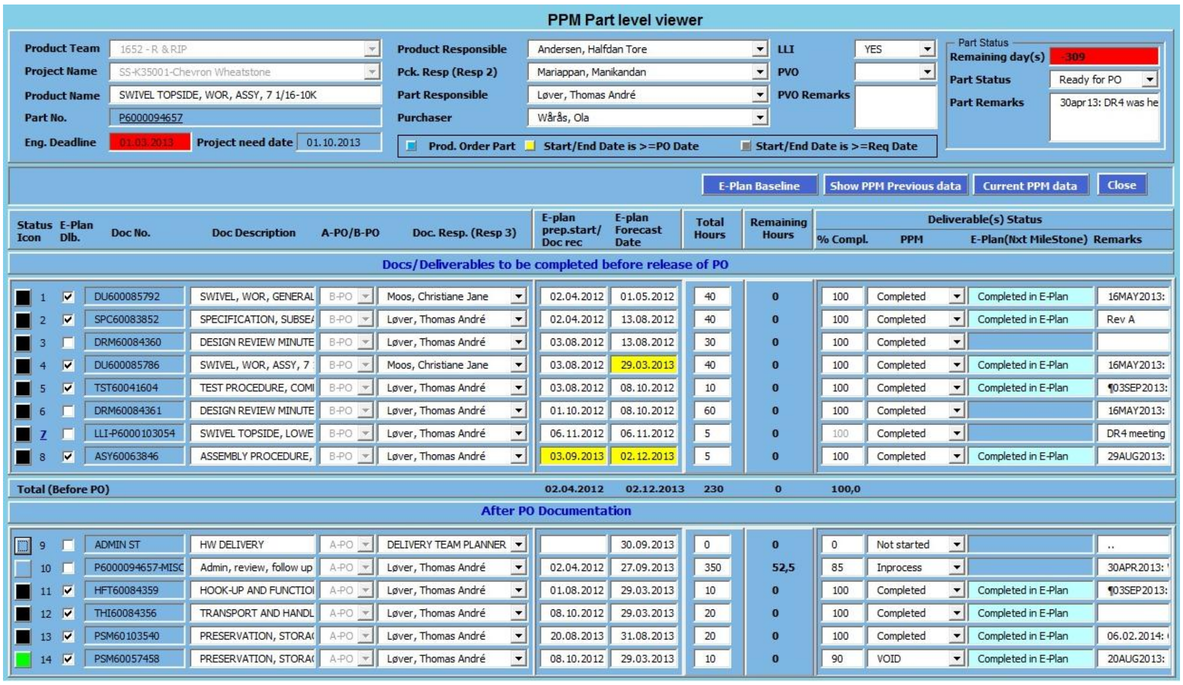

Figure 4.9: View from the PPM tool of one part.

The total amount of budgeted hours for the SoS is divided on different activities. The activities are given a document number, description, start date, end date, budgeted hours, and a responsible engineer. Some activities are added exclusively to the PPM tool. These are the activities with unchecked boxes for “Eplan Deliverable” in the view above. These activities do not produce a deliverable directly, but are necessary in order to conduct one or several of the other engineering activities, such as minutes of meetings from design reviews. Thus, the tool is updated with several extra activities in order to assign responsibility and track progress more correctly for each task.

An important function in the PPM tool is the possibility of flagging potential variation orders (PVO) when the engineers encounter a potential variation from the scope of work. A key success factor in order to get the PVO system working is to heighten the engineers' business awareness. Formerly, the client would go directly to the engineers to change design, material, etc. on a specific product, thus avoiding an invoice regarding the variation work. The PVO system would enable FMC to increase their profit on the projects by invoicing the client for VOs, but also locate changes by the client that have an effect on SoS delivery. This is an important function of the tool, and an important contribution to the organization.

4.2.2.3 The PPM Tool in the Organization

The PPM tool automatically updates Eplan with document status, and gets counter feed on new milestone dates. The status of progress serves as input for the planners when updating status in the Project and Product Plans. Consequently, the tool serves as input for the resource planning. In addition, both delivery teams and management teams simply download different kinds of reports directly from the tool, making it easier for all involved parties to track progress of the project. These links are shown in Figure 4.10.

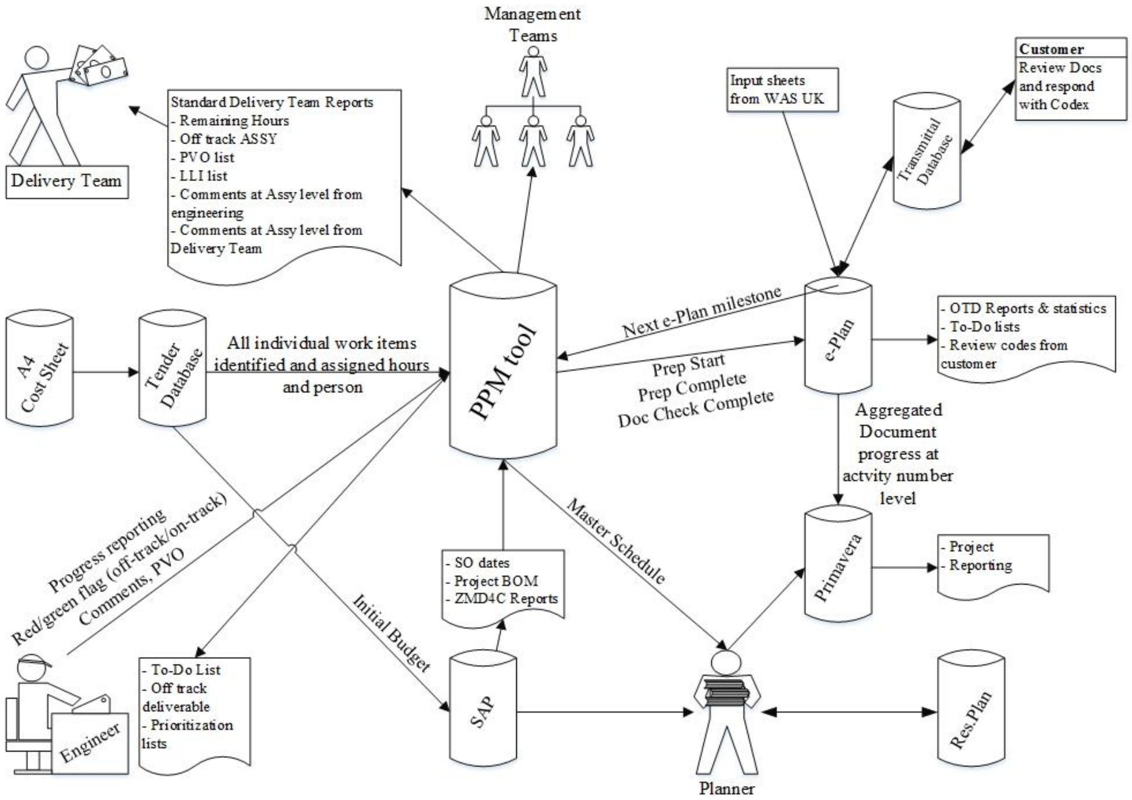

Figure 4.10: Planning tools in WAS.

The main purpose of the PPM tool is to serve as a common platform for all the project participants, including engineers, planners, delivery teams, and management teams, to get frequent status updates. Despite the fact that the PPM tool is mandatory to use, only five of 25 PPMs use the tool. It is argued that the tool is an unnecessary contribution to Eplan, and that some form of sequential planning, with less detailed progress reporting would be preferable. The previously described problems of quality in progress reporting are also used as an argument. It is stated that the frequent progress reporting only ends up in wild guessing, and consequently not contributes to a more reliable progress tracking. In addition, several similar tools exist in the organization. Thus, the engineers must report in different tools, depending on the department their work is connected to. This is obviously not an ideal situation in a large complex organization. The question remaining is then divided, is the PPM tool a necessary contribution to Eplan, or is it possible to have the same outcome by improving other currently used tools? Either way, how can the potential shortcomings of the situation today be strengthened?

4.3 IMPROVEMENTS IN THE PLANNING AND PROGRESS CONTROL

In this section, we have provided a summary of the discussion above. The shortcomings of both the tools and their usage, will serve as input when developing solutions to increase predictability in the project execution.

Problems with the initial planning:

- Inconsistent sequencing of activities occurs frequently. Urgent documents are planned too late, resulting in poor OTD, while non-urgent documents are planned too early, hence occupying resources. Thus, the prioritization of tasks threatens the final delivery.
- Poor resource allocation in the initial planning results in extensive workloads on individual participants.
- The activities are planned in parallel with long durations making it difficult to track the actual progress, allocate resources properly and avoid multitasking.

Problems with progress tracking:

- The PPM reports an estimate at completion (EAC) to the project management, as well as usage of hours, in order to track cost of activities. However, it is difficult to track the progress of each engineering activity, and monitor whether activities are on track or not. This is the reason for implementing a new tool, the PPM tool.
- The resources, or engineers, are not connected to one task at a time. Thus, it becomes difficult for the PPM to estimate new early finish dates, by only monitoring remaining hours.

Strengths and weaknesses of the PPM tool:

- The problems of insufficient order of activities is improved in the PPM tool, since the tool separates “Before PO” and “After PO” activities, thus increasing the awareness when planning.
- The PPM tool includes several activities that are not part of Eplan, e.g. support activities. These are not a part of Eplan since Eplan is shared with the client for monitoring of deliverables.
- The PPM tool encourages frequent status updates, which increase the awareness of each engineer, as well as commitment. However, the quality of the estimates is questioned.
- The PPM tool introduces a more progressive status tracking, compared to what Eplan offers. Thus, it is easier to track progress between “Doc. Prepared” and “Doc. Complete”. This is a shortcoming in Eplan, because more comprehensive milestone reporting requires extensive communication with the Document Controller.
- The PPM tool requires less communication with the Document Controller since reporting is done individually. However, the fact that the tool is “open” requires some quality improvements.
- The PPM tool offers a more comprehensive view of documents, drawings and other activities related to each part of the BoM structure, compared to Eplan. This makes it easier for each participant to analyze off-track impacts. In addition, the engineer will find relevant information about the other participants.
- The PPM tool is cost focused. Since resources are used in parallel activities, the estimates of remaining hours represent a cost issue, rather than a delivery issue. Further, it is impossible for the PPM to know whether the engineer will make it in time or not, unless the engineer flag his/her activity appropriately.
- The PPM tool has a major advantage with the PVO flagging. This enables communication between the project / contract engineer, and each participating engineer regarding any potential variation orders. This is not a function that can be easily implemented in Eplan.

These findings are evaluated against the new framework in Section 8.1.

5 THEORIES, METHODS AND CONCEPTS

In this chapter, we present the theories, methods and concepts used in the thesis. The purpose of the chapter is to give the reader a comprehensive understanding of the theoretical background used to answer the research question presented initially. We have undergone a thorough literature review into the different theories and methods presented here, and the sections serve as summaries of the most important aspects of each. First, we show that design theory is concerned with increasingly more complex activities, where knowledge and problem-solving develop gradually through iterations and learning. Second, we present research into coordination theory, concentrating on dependencies and the complexity associated with the coordination of these. Especially, mutual adjustment, which is concerned with eliciting commitments and fostering learning, seems to be of importance when dealing with complex relationships between activities. Third, three approaches to planning and production control within design is presented, namely the Last Planner System, Critical Chain Project Management, and Scrum, all of whom deal with mutual adjustment in their own way, followed by a short description of the traditional Critical Path Method. Finally, a comprehensive comparison of the approaches used for planning and production control is presented alongside an analytical model.

5.1 DESIGN THEORY

The concept of design as a problem-solving activity is the most widely known and accepted perspective of design (Male et al., 2007). Generally, design is about conceiving things that meet specifications and requirements. Thus, engineering design is the process of creating a technical solution to solve a given problem (Smith & Eppinger, 1997). A design problem will include balancing a range of requirements against constraints determined by technology, materials, production methods, market considerations, and human factors, i.e. physical and psychological characteristics of the users. Koskela, Huovila, and Leinonen (2002) argue that the design process may be conceptualized in at least three different ways[8]: (1) transformation, (2) flow and (3) value generation. Design as transformation is a way of transforming requirements and other input information into product designs. A central notion to this conceptualization is a hierarchical decomposition of activities in order to increase the transparency among the members of the organization, known as Work Breakdown Structure (WBS). However, significant features like time and customer needs are not included in this

[8] The TFV-model was originally presented by Koskela (2000).

conceptualization, i.e. the flow and value generation concepts are neglected. The flow concept views design as a flow of information, composed of four different stages, namely transformation, inspection, moving and waiting. The main principles are elimination of waste[9], time reductions and reduction of uncertainties. Waste in design arises from waiting, delays, over-processing, design errors (Kpamma & Adjei-Kumi, 2011), and unnecessary iterative loops, also known as negative iterations (Ballard, 2000b). The value generation concept views design as a process where value is created through fulfillment of customer requirements. The basic thrust is to eliminate value loss from the point of view of the customer. Dym, Agogino, Eris, Frey, and Leifer (2005, p. 104) capture the essentials of the nature of engineering design in their definition:

"Engineering design is a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints."

Although the design process accounts for a small percentage of the total project cost, it significantly determines the characteristics and eventual outturn cost, both in regards to capital and life cycle terms (Male et al., 2007). In addition, defects and shortcomings in the final delivery may be traced to decisions during the design process. Furthermore, Josephson and Hammarlund (1999)[10] found that design-caused defects played a vital role in cost overruns. Also, Sverlinger (1996) argue that the most frequent causes of severe design deviations were deficient planning or resource allocation, missing input information, and changes.

The nature of the design process is complex, as it involves thousands of decisions, sometimes over several years, with numerous interdependencies in an inherently uncertain environment (Freire & Alarcón, 2002). With both market competition and increased demand for efficiency, quality, safety and additional specifications from the clients, design should be a priority. Thus, in order to develop complex products and large-scale engineering systems, it is common practice to decompose the design problem into smaller sub-problems, which can be handled more easily (Eppinger, 1997). A key success factor in order to achieve an integrated system in the final product is to implement good design management at the various levels. Well-executed design management would enable the project participants to gain a deeper understanding of the client's strategic goals and to structure dialogue among the participants. Further, design management would involve improving interdisciplinary working between

[9] Waste was first defined by Toyota (Ohno, 1988), where seven non-value generating activities were found.
[10] Design-caused defects were the major category for cost overruns in three out of seven projects.

different design disciplines on complex projects and achieving efficiency in the design process with a minimum of unnecessary iterations. Thus, design inevitably involves both positive iterations that help improve product quality, and negative iterations that do not add value (Hamzeh, Ballard, & Tommelein, 2009). Smith and Eppinger (1997) propose two ways to accelerate an iterative development process: (1) to execute faster iterations, or (2) to conduct fewer iterations. Faster iterations are achieved through several means, such as the use of engineering models or information technology. Fewer iterations may be experienced by anticipating results from other activities, or when extraneous activities are removed from the iterative portion of the process. Solutions to the iteration problem may include adding resources, restructuring the process, redefining the problems, reassigning tasks, etc. In addition, complex projects tend to perform concurrent engineering, i.e. a number of engineering activities are underway at one time, and the entire set of activities converges to the design solution at once (Hoedemaker et al., 1999). When conducting parallel tasks, a key issue is to avoid unnecessary iterations and rework, but traditional planning techniques take little account of the interdisciplinary, iterative nature of the design process (Austin et al., 1999). Inevitably, this leads to cycles of rework, as well as time and cost penalties in both design and fabrication.

Due to the nature of the design process, planning serves as a challenging task. Traditionally, several planning strategies used in the design process are based on linear approaches, such as “Stage Gate” and “Waterfall” (Kalsaas, 2013), or the Critical Path Method (CPM) (Kelley Jr & Walker, 1959). Austin et al. (1999) argue that the traditional planning techniques are unsuitable for design work because they are incapable of dealing with the effects of variations and delays in iterative processes such as design. Further, they track progress in retrospect based on completion of deliverables, as opposed to the availability of key information needed for future activities, i.e. they neglect the soundness of required input. Experience with linear models have shown that they fail to fully capture the dynamic nature of engineering design, where knowledge and problem-solving develop gradually through learning processes (Kalsaas, 2012). In addition, planning and control seem to be substituted by chaos and improvisation in design (Freire & Alarcón, 2002), causing poor communication, deficient or missing input information, unbalanced resource allocation and lack of coordination between disciplines and actors. Thus, planning design and engineering through iterative and inclusive methods fostering collaboration and commitments must be sought, in order to improve predictability and quality of the deliverables.

5.2 COORDINATION THEORY

Due to the inherent complex nature of the design process, coordination of the dependencies between tasks and resources serve as an important practical problem for many organizations. In this perspective, the coordination mechanisms play a vital role for managing dependencies in the process. In a way, the processes in an organization describe several important aspects of the organization. Thus, focusing on how tasks are performed, in regards to the overall process, is a good way of narrowing the study of an organization (Crowston, 1997). The idea to focus on the overall process rather than the tasks themselves coincide with the flow conceptualization by Koskela et al. (2002). Kalsaas and Sacks (2011) argue that a better understanding of different types of dependencies among management members will lead to better decisions when organizing work, either by avoiding the most complex dependencies or meeting them with awareness. They also point out that it does not seem to be a broad understanding of the limitations planning or scheduling has as a coordination method, and that planning often fails to give the desired result. Thus, we will describe different types of dependencies and the associated coordination mechanisms used to manage them.

Malone (1988) defines coordination as the extra activities needed for organizing multiple, connected actors pursuing the same goal. The goal must be seen as the overall goal of the organization, or related to the process. Each individual actor may not have the same goal due to specialization of tasks. Thus, coordination theory describes how these activities can be coordinated. In addition, Crowston (1997) claims that coordination problems between actors arise due to dependencies that constrain how tasks can be performed. In other words, coordination is concerned with the dependencies between actors or activities. When we look at coordination as a form of managing dependencies, it is important to have in mind that other forms for managing dependencies exist, e.g. “political processes” (Malone & Crowston, 1994). However, such is outside the scope of the thesis. Coordination as a management tool for designing tasks and assignments may be traced back to J. G. March and Simon (1958), who argue that coordination is more than dividing work and assigning it to actors. They address the problem of arranging a signaling system for interdependent activities, and describe it as the “coordination problem”. A coordination mechanism to solve this problem is what they express as “self-containment of tasks”, a simplification by breaking the process into nearly independent tasks (Crowston, 1991). However, such simplification is not necessarily possible with design activities due the inherent complex nature.

Thompson (1967/2003) identified three different dependencies that can be found internally in complex organizations: pooled, sequential and reciprocal, as shown in Figure 5.1. The dependencies are defined by the flow of work, materials and objects between units. There are different management measures and modes to coordinate the different dependencies.

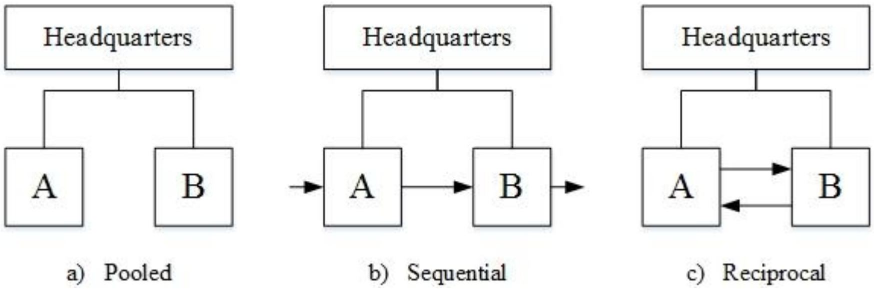

Figure 5.1: Pooled, sequential and reciprocal dependencies (Galbraith, 1968, p. 7).

Pooled dependence is the least complex, which has a weak constraint between the tasks or actors. Van de Ven, Delbecq, and Koenig Jr (1976) actually call this "independent". The pooled form of dependence is what we find between different "standalone" departments within an organization. The organization relies on the success of each department, but each department is not directly affected by the actions of the others. Thompson (1967/2003) argues that standardization, e.g. routines, may guide each participant to act according to what is best for the overall organization. Coordination by standardization is the most effective method for pooled dependencies, as they are codified and require minimal verbal communication when implemented (Van de Ven et al., 1976).

Sequential dependencies have a stronger relationship compared to pooled dependencies; thus, coordination becomes increasingly important. Each sequential task must be completed in order for the next to start, i.e. unit B depends on the completion of the task at hand by unit A. However, the task at hand by unit B is fully defined and the only requirement is that the previous task is completed. Sequential dependencies are often found in plans and schedules. A schedule will ensure sufficient coordination of related units, as well as visualizing impact of changes. This coordination method will also reduce some of the bureaucratic forms of coordination by standardization.

If unit B is dependent upon the output of unit A, the dependence is reciprocal (Thompson, 1967/2003). This is a situation we might find at the hospital when a patient arrives at the emergency. The output of the first unit, i.e. the patient arriving, gives input to whatever needs to be done next, or whom to contact, e.g. different specialists. Further, Thompson (1967/2003) argues that these dependencies will occur based on the complexity of the organization. All organizations will have pooled dependencies, more complex will consist of both pooled and sequential, and the most complex organizations will consist of pooled, sequential and reciprocal dependencies. The increasing complexity in the dependencies also implies that the coordination mechanisms are more complex for reciprocal than for pooled dependencies. While plans and schedules are sufficient coordination methods for sequential dependencies, they are less efficient when reciprocal dependencies occur. Galbraith (1968) argues that pre-established rules and plans will have limited capacities to handle the unpredictable nature of reciprocal dependent units. This is obvious if we look back at the patient example above; planning the sequential line of action would not be sufficient since the circumstances must be clarified in order to plan the right action. To coordinate reciprocal dependencies, Thompson (1967/2003) suggests mutual adjustment or feedback. This form of coordination involves direct flow of information, allowing each actor to adjust to the other. Thus, the coordination method is far more inclusive in terms of communication and decision-making.

As a contrast, Mintzberg (1979) describes a similar set of coordination mechanisms (Crowston, 1994): mutual adjustment, direct supervision, and standardization by work processes, outputs and skills, whereas each mechanism is most prominent in different organizational structures or environments (Crowston, 1991). In other words, Mintzberg studied coordination mechanisms in relation to the organizational structure, while Thompson described mechanisms for coordination by evaluating internal dependencies.

Van de Ven et al. (1976) build upon the early works of Thompson (1967/2003) and extends his work by a fourth interdependency; “team arrangement”. It is a team workflow similar to what we find in sports, where the actors diagnose, solve problems and collaborate jointly to execute the process. The difference from sequential and reciprocal dependencies is that there is no lapse in the workflow. They also build upon the work by J. G. March and Simon (1958), who state that organizations can be coordinated either by programming or feedback, where the former refers to standardization and plans in Thompson’s view, what Van de Ven et al. (1976) describe as impersonal mode, and the latter is similar to mutual adjustment based on new information. However, they define two additional operational modes, based on organization theory, for mutual adjustment: a personal mode and a group mode. The personal mode sets the person in center, and the individual serves as the mechanism to ensure mutual adjustments with vertical or horizontal forms of communication. The vertical form is communication through vertical channels, i.e. hierarchy, and the horizontal form is communication directly with other role actors. The group mode is mutual adjustment through scheduled and unscheduled meetings, where coordination is done with the task or group in center, i.e. team arrangement. An interesting finding in their study is that when the uncertainties of the tasks increase, we see a decrease in the use of impersonal coordination (plans, standardization, rules, etc.) and an increase in the use of personal and group coordination. In addition, they found a decrease of vertical communication and a significant increase in horizontal forms of communication. This implies that when the tasks become more variable, adjustments are made among other role actors rather than superiors. However, when the dependence in the workflow increased, e.g. from pooled to team, it was found an increase in all coordination mechanisms.

Crowston (1991) criticizes Thompson’s work because it does not indicate how dependencies in real organizations can be identified, apart from the nature of the interactions. Thus, it is unclear whether it was the organizational structure that made the dependencies, or vice versa. Crowston (1994) claims that most researchers within the field, including Thompson, only looked at the actors and their tasks in relation to the interdependence, and hence viewed the dependency as given. The goal is then to identify proper coordination mechanisms to manage the dependencies, rather than assigning tasks to create desired dependencies or reduce undesired dependencies. However, whether we look at the dependencies as given and seek the best form for coordination, or look at the dependencies between tasks for designing the right workflow and using the right coordination mechanisms, the most important aspect of coordination is to understand the effects of the dependencies.

Sequential planning is a well-known coordination mechanism. However, traditional planning methods seem to be inadequate when dealing with design activities, which have a high degree of reciprocal dependencies. Yet, one way of planning engineering activities is to utilize a Design Structure Matrix (DSM) in combination with traditional planning methods (Steward, 1981). As argued earlier, engineering design involves the specification of a set of variables, which together define a product. However, some variables cannot be determined until others are known or assumed. Thus, there is a precedence order of the variables. DSM can be used to organize the design of a system, develop an effective engineering plan and analyze the flow of information that occur during the design work (Steward, 1981). The purpose of the DSM is to highlight the current dependencies between tasks, and then decide the optimal ordering of activities. In Figure 5.2, ten activities and their dependencies are listed. Along the horizontal axis, activities that provide input to other activities are listed, while receivers are listed vertically. “X” marks a dependency: an X above the diagonal line represents reciprocal dependencies, while an X below marks sequential dependencies. As an example:

- Task B provides information to tasks C, F, G and I.
- Task D receives input from tasks E, F and J. However, these tasks are planned later than task D. Optimally, these should be performed before D.

Receive \ Provide	A	B	C	D	E	F	G	H	I	J
A	●		X							
B		●								
C		X	●							
D				●	X	X				X
E					●	X		X	X	
F		X				●	X			X
G		X	X				●		X	
H	X		X			X		●	X	
I		X	X						●	
J	X						X	X	X	●

Figure 5.2: Example of a Design Structure Matrix.

After a restructuring, some reciprocal dependencies might still occur, and these should be coordinated by mutual adjustment, which is not implemented in traditional methods. Macomber and Howell (2003) argue that a reliable workflow is important for improving productivity, and the most important aspect is to increase predictability for downstream assignments. Each assignment should be a promise to the actors downstream. This promise perspective can be understood in accordance with the linguistic action perspective (LAP), which is one way of understanding the effects of coordination by mutual adjustment.

5.2.1 Linguistic Action Perspective

According to Macomber and Howell (2003), LAP goes beyond coordination and includes a series of domains, but we are mainly concerned with the "coordination of action" and "assessment" aspects of the theory. All projects include humans as resources, and humans have the capability to learn, improvise, assess, cooperate, etc. This is essential in the uncertain environment of a project, and gives us the capacity of making and keeping commitments (Macomber & Howell, 2003). As Winograd and Flores (1986) put it, humans act in way were we generate commitments through our daily communication. If we were unable to create and accept commitments, we would be acting in a less human way. Furthermore, as the project evolves, the team members will assess risks and opportunities, which in turn will provide more accurate information for the project (Macomber & Howell, 2003). Different backgrounds and personalities might also unveil information that is in a blind spot for others. Thus, the team members must be able to continuously carry out their work and commit when new information unfold (Macomber & Howell, 2003). Eliciting commitments, or reliable promises, is thus of great importance for the project, which is in accordance with the coordination mechanism of mutual adjustment. In addition, Kalsaas (2013) support this view by stating that engineering activities require both formal meetings and frequent informal conversations, i.e. mutual adjustment, for developing the object and addressing problems defined by different disciplines, not only one's own. This form of mutual adjustment may be associated with "positive iterations" (Ballard, 2000b; Kalsaas, 2013). According to Macomber and Howell (2003), the problem with linear scheduling of activities is that these methods fail to secure promises; the planning is based on the intentions and perspectives of the management, and the activities are managed as if machines accomplish them. Thus, coordination by plans, containing tasks characterized by reciprocal dependencies, is difficult or impossible, and requires supplementary coordination by mutual adjustment (Kalsaas & Sacks, 2011). In addition, mutual adjustment fosters learning through feedback cycles intended to identify improvements to implement in the next planning period.

5.3 PLANNING AND PRODUCTION CONTROL METHODS

In this section, we will present four different approaches to planning and production control, namely the Last Planner System, Critical Chain Project Management, Scrum and Critical Path Method. The three former are inclusive and iterative planning and production control methods concerned with how coordination by mutual adjustment can be applied in practice to increase predictability and quality of the deliverables. These have been developed as a critique or response to traditional planning and control. The latter is a traditional planning method, which we present in short, to highlight the contrast between traditional and inclusive methods.

5.3.1 Last Planner System

The Last Planner System of Production Control[11] (LPS) is a trademark of the Lean Construction Institute. The system has been developed by Ballard and Howell since 1992 (Koskela, 1999), and has in recent years been developed through the International Group for Lean Construction (IGLC) community. Initially, LPS was developed to improve productivity as an extension of the quality management and productivity improvement initiatives that dominated the construction industry in the 1980's. However, LPS shifted towards improving the reliability of workflow as a consequence of the revolution in manufacturing inspired by the Toyota Production System (Ballard, 2000a). This shift is in accordance with the flow conceptualization in the TFV-model developed by Koskela (2000). LPS, also referred to as collaborative planning (Mossman, 2013), is based on Lean principles and seeks to improve the quality and reliability of schedules through collaboration; thus increasing productivity (Kalsaas, 2012). Planning tools inspired by the Last Planner System provide an alternative to

[11] Production control is monitoring of performance against project specifications (budget, plans, constraints, etc.) and corrective actions needed to conform performance to the specifications (Ballard & Howell, 1998).

the linear approaches of organizing and managing design and engineering processes (Ballard, Hammond, & Nickerson, 2009; Hamzeh et al., 2009; Kalsaas, 2013). According to Ballard et al. (2009), there are five main principles in LPS:

- Plan in greater detail as you get closer to performing the actual workload.
- Produce plans collaboratively with those who will perform the work.
- Reveal and remove constraints on planned tasks as a team, i.e. ensure soundness of tasks.
- Make and secure reliable promises.
- Learn from failures.

The LPS methodology implements four different levels of planning: (1) the Master Schedule, (2) the Phase Schedule, (3) the Lookahead Plan, and (4) the Weekly Work Plans (Ballard, 2000a). In addition, a feedback and learning system is implemented (Kalsaas & Sacks, 2011; Koskela et al., 2010).

The Master Schedule is the top level of planning and a result of the initial planning. The plan points out what should be executed, as well as the main activities and milestones of the project. The plan visualizes the overall activities with durations, sequence and division into work packages. Also, it serves as guidance for lower level planning (Koskela et al., 2010).

Based on the Master Schedule the project is divided into main phases. Thus, the Phase Schedule is the second level of planning which secures a thought through sequence and structure of work (Ballard, 2000a). The quality of the Phase Plan depends on active engagement of different trades and actors involved in the project for agreement on the common output of the planning. The planning is done by "reverse scheduling" or "pull scheduling", with the desired milestone dates as the origin. All the activities necessary to reach the milestones are planned backwards by identifying handoffs between trades and actors, which restrict the sequence of work, thus it describes what "should" be done. Phase Scheduling is an important part of LPS, as Ballard and Howell (2003, p. 2) point out:

"Phase Scheduling is the link between work structuring and production control. Without it, there is no assurance that the right work is being made ready and executed at the right time to achieve project objectives."

The Lookahead Plan represents the planning window in the nearest future. The function of the Lookahead is to shape workflow sequence and rate, and match workflow and capacity by collaborative planning (Ballard, 2000a). Also, the Lookahead is used to identify constraints for removal, elicit commitments to remove the constraints, and break down activities into an operational level of detail (Hamzeh et al., 2008). Each activity in the Lookahead Plan shall be evaluated in terms of their preconditions (Ballard, 2000a). The state of the task is based on whether it is sound or not (Koskela, 1999). The soundness of a task is based on the work by Ronen (1992), who suggests that work should not start until all necessary inputs to complete the task are available. This is in accordance with the theory of waste in Lean Production where any hindrances in the production flow, like unnecessary transportation, waiting etc. is reduced or removed (Howell, 1999). Koskela (1999) defines seven forms of preconditions to make a task sound: design, components and materials, workers, equipment, space, connecting activities, and external conditions, but he also states that more preconditions can exist. Koskela (2004) further develops his view on soundness to what he describes as "making-do", the situation when an activity is started without the availability of an input, nor the optimal situation of that input. Thus, by implementing Lookahead Planning, "making-do" may be avoided. Sound activities are placed in the "Workable Backlog", which must be maintained throughout the project, and contains activities that "can" be done.

The Weekly Work Plan is a plan of the next week's upcoming task. Sound activities are selected from the Workable Backlog, and binding commitments are made. The committed tasks must be well defined, in the right sequence, and aligned with the team's capacity (Ballard & Howell, 1994). Tasks that are not sound, but implemented in the Lookahead Plan, are avoided. The Weekly Work Plan meeting is an arena for coordination by mutual adjustment. Also, safety and quality issues, execution methods, etc. for upcoming tasks are discussed. Thus, the Weekly Work Plan should have a high degree of feasibility (Kalsaas & Sacks, 2011), describing what "will" be done.

The feedback and learning system is a measurement of what is actually done in the project. It is based on the Percent Plan Completed (PPC) method, which measure the amount of tasks completed in relation to planned tasks. As Koskela et al. (2010) put it, PPC is measurements of promises made that are delivered on time. Howell and Macomber (2002) argue that the management should ask the performers whether the work promised to be done is completed or not, and that no honor should be given for tasks completed that are not a part of the plan. This is because unscheduled work might need rework later due to changed input. They also point out that the PPC should be presented, e.g. graphical on the wall, to visualize the status of the project for the team members. The monitoring also includes an analysis of reasons for non-completed tasks, e.g. ask "why" five times in a row to identify the root-cause (Kalsaas, 2012), which is input for improving the project planning and execution in the future, i.e. reduce or prevent reoccurrences of reasons for non-completion. Howell and Macomber (2002) suggest that these causes also should be visualized for the project, e.g. a Pareto chart.

LPS is tested on construction tasks (Ballard, 2000a), which are more or less predictable in terms of their content. Design, however, emerge through a complex process, thus we cannot fully predict the sequence of work initially (Ballard et al., 2009), as new unforeseen design activities might be unveiled during the process. Production control during design are distinguished by three factors: (1) uncertainty of ends and means reducing the ability to foresee the sequence of future tasks, (2) the speed of execution, and (3) the interdependencies between design tasks that increase complexity and planning functions. Ballard (1999) argues that design criteria and solutions evolve as the process progresses, which is what Thompson (1967/2003) describes as reciprocal dependencies. Yet, the rule to collaboratively plan in greater detail closer to the event still applies to design activities, but the forecast period must be shortened (Ballard et al., 2009).

LPS might be summarized as four mechanisms (Ballard & Howell, 1994), for ensuring that what “should” be done is made sound and thus “can” be done, and through commitments “will” be done, as well as continuous learning to improve the next planning period, which is illustrated in Figure 5.3. Thus, it represents a shift in project management, from controlling by after-the-fact monitoring to collaborative planning by engaging the people performing the work (Neil, 2011). Project coordination and control in LPS is thus a practice of eliciting reliable promises and following up on declarations of completed work for downstream activities (Howell & Macomber, 2002), which is in accordance with LAP. Planning is then about conversation, collaboration and commitment, i.e. mutual adjustment.

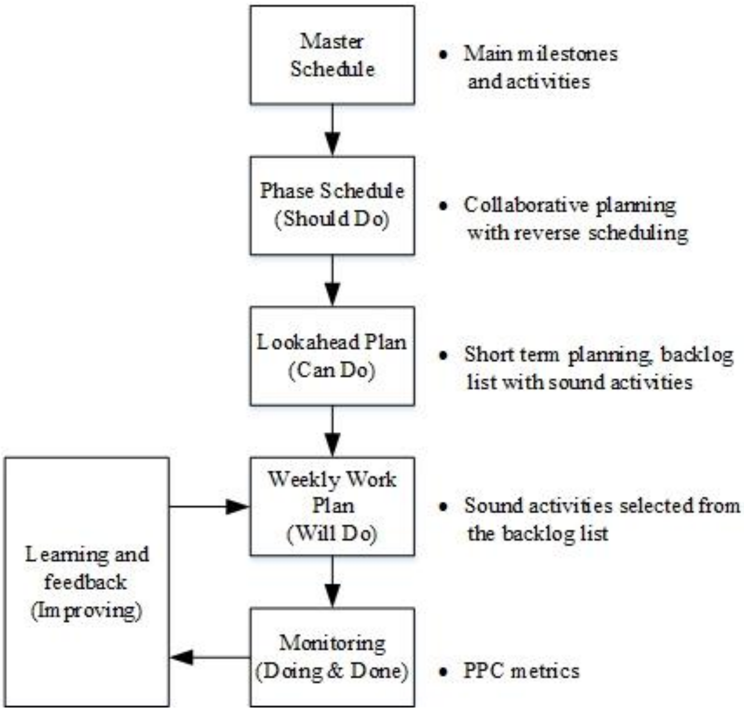

Figure 5.3: The Last Planner System of Production Control.

As Kalsaas and Sacks (2011) point out in their article, even though Phase Planning, Lookahead Planning and Weekly Work Planning in many ways accomplish mutual adjustment, LPS does not have any method for mutual adjustment as execution of the Weekly Work Plan commence. The more recent contribution to LPS from Macomber, Howell, and Reed (2005) also address the need for regular re-promising, as the future is uncertain, and daily promise meetings are proposed. Kalsaas and Sacks (2011) argue that it is crucial to perform an analysis of the dependency structure and coordinate more closely through mutual adjustment, where needed, to avoid large buffers of work. They also point out that even for sequential dependencies in sub-projects it might exist reciprocal dependencies through the relationship of resources involved in other projects, i.e. multitasking.

A potential shortcoming of planning tools as LPS is that they do not contain linear approaches necessary to report progress, cost and quality (Kalsaas, 2013). Thus, a planning tool for design and engineering activities should contain both iterative and inclusive methods, such as LPS, and linear methods.

5.3.2 Critical Chain Project Management

Critical Chain (CC) or Critical Chain Project Management is a project management method, based on the Theory of Constraints (ToC) from production management (Rand, 2000). The theories, and their application, are originally ideas of Eli Goldratt (1997). ToC is in short a system to coordinate production in relation to the constraint of the system, i.e. the bottleneck (Rand, 2000). The idea is to exploit the constraint in terms of throughput by optimizing all other connected units, i.e. releasing the correct workflow into the system in proper time to avoid starvation or overloading of the constraint (Leach, 2000). If the constraint is somehow elevated, a search for a new constraint will be necessary (Rand, 2000). Thus, the system is based on continuous improvement.

The application of the theory in project management is based on two main ideas: a more global mindset, and buffer management of constraints, i.e. uncertainty (Rand, 2000). The chain of activities is not made upon the precedence dependency alone, making a critical path, but also by the use of resources. The resource and activity planning is based on backward scheduling, as with LPS (Shen & Chua, 2008). Whenever an individual resource is used in parallel activities, the critical chain will be longer due to the fact that a resource should be assigned to one task at a time, as illustrated in Figure 5.4. This is a way of ensuring flow, and avoiding multitasking between several projects (Koskela et al., 2010). Goldratt (1997) refers to what he call the Student Syndrome when explaining the problem of uncertainty management in CC. When safety estimates are built into every activity, there is a tendency not to go at full thrust because of the long duration. This might also be linked to the Parkinson's Law, stating that work expands to fill the time available (Shen & Chua, 2008). Another problem is that the next activity will not be ready to start up immediately, since it is uncertain when the previous will finish (Rand, 2000). A third problem is the fear of completing prior to the estimate, resulting in a shorter budgeted time in the next project. The idea in CC is to avoid safety estimates in the activities by applying safety buffers at the end of the activity chain, thus reducing the length of the critical path. There are two forms of buffers: feeding buffer and project buffer. These are illustrated in Figure 5.4. The feeding buffer is related to chains of non-critical activities that must be completed in order to perform activities at the critical chain. These must be finished some time prior to the actual need date, in order to cope with the problem of unfinished preceding tasks, i.e. "making-do". The project buffer is a safety buffer for the critical chain. Thus, the CC approach exploits the fact that it is not the task that should be on time, but the project as a whole (Koskela et al., 2010). It is argued that moving the buffers and shortening the duration of each task, will remove the Student Syndrome, and the above-mentioned problems. It is also argued that the buffers, in total, might be reduced, thus shortening the project duration (Rand, 2000).

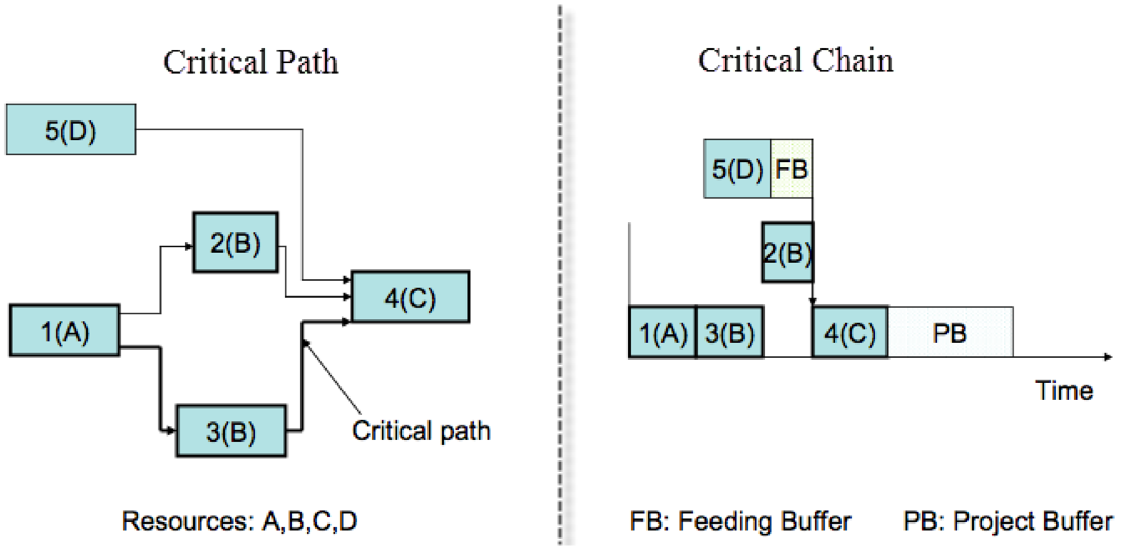

Figure 5.4: Critical Path vs. Critical Chain (Stratton, 2009, p. 160).

It is not only the planning technique that distinguishes CC from CPM; it is also the control of project execution. As with the ToC, monitoring for improving the system is needed. The monitoring is based on a simple projected time to completion for each task, rather than financial progress reporting, thus making it easier to report more frequently (Koskela et al., 2010). This will also provide more visibility for upcoming tasks, referred to as resource buffers. A resource is then provided, among several projects or tasks within the project, according to a priority system. The system is based on the critical chain completed to project buffer consumed ratio. When buffer consumption occurs, the awareness of consuming off-track time will be more visible, and proper actions might be taken sooner. In addition, it will be easier for the management to trace and support the actual activity, since theoretically only one activity consumes buffer at any time. The control at the project level will differ from the activity level. If the delivery date is threatened by buffer consumption, other actions must be considered, e.g. review plans, provide additional resources, etc. In recent descriptions by Goldratt it has also been described a need for monitoring reasons for buffer consumption, which act as input for further improvement (Koskela et al., 2010). CC secures mutual adjustment indirectly by frequent progress reporting and synchronization with other activities and resources. Thus, the CC method is more iterative and inclusive than traditional methods.

5.3.3 Scrum

Scrum is a framework for developing and sustaining complex products, while productively and creatively delivering products of the highest possible value (Schwaber & Sutherland, 2013). The framework consists of Scrum Teams and their associated roles, events, artifacts, and rules. Scrum Teams are self-organizing and cross-functional. Self-organizing because they choose how best to accomplish their work, and cross-functional because they have all the competencies needed to accomplish their work. The team model is designed to optimize flexibility, creativity and productivity. Furthermore, Scrum employs an iterative, incremental approach to optimize predictability and control risk (Schwaber & Sutherland, 2013). The framework was developed in response to the traditional planning methods, such as the Waterfall method, because they failed to predict, failed to deliver on time, produced less functionality per developer, and neglected customer involvement or requirement alterations, resulting in poor user satisfaction (Sutherland, 2004). Thus, in accordance with LPS and CC, the method was developed as a response to problems with traditional methods.

Scrum consists of three pillars, (1) transparency, (2) inspection, and (3) adaption (Schwaber & Sutherland, 2013). Transparency is a significant aspect of Scrum, because the overall process must be visible to those responsible for the outcome, i.e. a shared understanding of requirements achieved through a common language and definition of when the work is “Done”. Inspections are performed frequently to ensure progress and detect undesirable variances from the goal. Adaptions must be made when the process deviates from the acceptable limits or when the resulting product is undesirable.

There are four Scrum Events: formal opportunities to inspect and adapt, specially designed to allow transparency (Schwaber & Sutherland, 2013). These are the Sprint Planning, Daily Scrums, Sprint Reviews, and Sprint Retrospectives.

The Sprint Planning is performed in collaboration with the entire Sprint Team, and the outcome is a Sprint Goal for the planned period. The Sprint Goal is an objective that can be met within the period. It serves as guidance for the Scrum Team, and is somewhat flexible regarding the functionality of the product increment. These periods, or Sprints, are the main processes of Scrum. Through the Sprint Goal, each Sprint gets a definition of what to be built, a design and flexible plan that will guide building it, the work, and the resultant product. A Sprint is time-boxed to one month or less, during which a "done", useable and potentially releasable product increment is created. Any longer horizon may result in changes to what is being built, the complexity and risk may increase. Thus, Sprints enables predictability by ensuring inspection and adaption towards the Sprint Goal at least once a month.

Daily Scrum meetings, time-boxed to 15 minutes, are held in order to synchronize activities for the upcoming 24 hours. The meeting includes investigation of progress towards the Sprint Goal since the last daily meeting, and a forecast of activities until the next. The purpose of the Daily Scrum is to ensure high probability of meeting the Sprint Goal. Daily Scrums improve communication, eliminate other meetings, identify constraints for removal, highlight and promote quick decision-making, and improve the team's level of knowledge.

Sprint Reviews are held at the end of each Sprint. In the Sprint Review, the participants collaborate to investigate what was done during the Sprint. Based on the investigation, they collaborate on the next activities to optimize value for the customer. The meeting is informal: it promotes feedback and fosters collaboration, which results in a revised Backlog. The Sprint Retrospective is a collaborative investigation of the Sprint: an opportunity to investigate the performance of the team and propose improvements to implement in the next Sprint.

Scrum Artifacts represent value or work to provide transparency and opportunities for inspection and adaption (Schwaber & Sutherland, 2013). The most important artifacts are (1) Product Backlog, (2) Sprint Backlog, and (3) Increments. The Product Backlog is a list of everything needed in the Product and the single source of requirements for any changes to be made to the product. It lists all features, functions, requirements, enhancements and fixes needed for the final product. Product Backlog items that can be "done" within the Sprint are defined as "ready". The Sprint Backlog is a subset of the Product Backlog selected for the Sprint, including prioritized activities, a plan for the Sprint and a Sprint Goal. It visualizes all the work needed to meet the Sprint Goal. Emerging factors may occur while they work through the plan and learn more about the work needed to meet the Sprint Goal; these are implemented in the Product Backlog. The Sprint Backlog is updated with new work, completed items, and estimation of remaining work, and is a highly visible, real-time picture of the work during the Sprint. An Increment is the sum of all Product Backlog items completed during a Sprint. The Scrum process is illustrated in Figure 5.5.

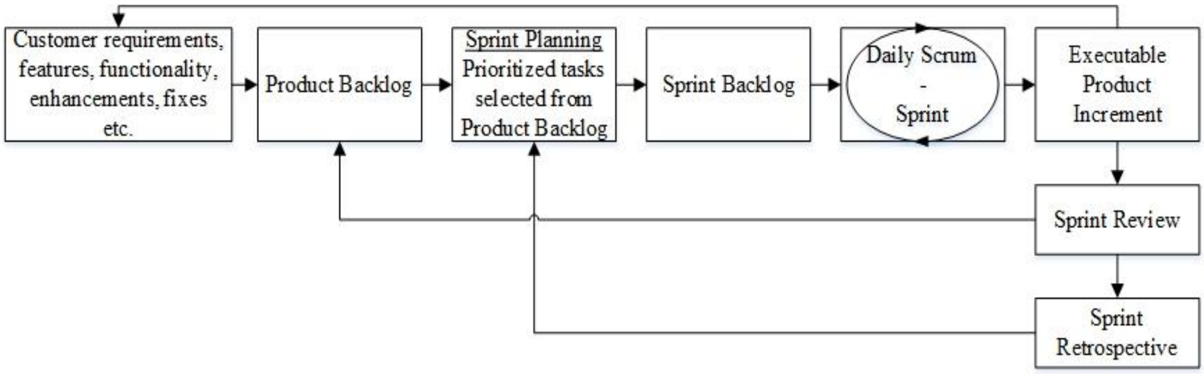

Figure 5.5: The Scrum framework.

5.3.4 Critical Path Method

In the Critical Path Method (CPM), activities are defined such that they can be fully completed before subsequent activities commence (Kelley Jr & Walker, 1959). Thus, the tasks are mutually independent, expect the relationship to preceding activities (Koskela et al., 2010). Further, the activities are defined with durations and precedence relations across all project functions (Kelley Jr & Walker, 1959). Activities are the central unit of analysis in CPM, describing the order and timing of the tasks (Koskela et al., 2010). The critical path is the path of activities that are in direct relation throughout the project, and thus define the duration of the project, which can be visualized in a diagram with coupled activities (Kelley Jr & Walker, 1959). The plan shall function as guidance, and makes rigorous limits to guide personnel. In addition, planning is a higher managerial role in CPM, thus lacking a domain for collaborative planning across several involved actors, i.e. central control is assumed necessary (Ballard, 2000a). Further, CPM pushes work into execution without considering the soundness of the tasks (Kalsaas, Grindheim, & Læknes, 2014).

5.4 COMPARISON OF LPS, CC, SCRUM AND CPM

This chapter has presented relevant aspects to consider when planning complex engineering and design activities, as well as theories and methods for practical implementation. Thus, this section will present a comparison of the different methods. We summarize the comparison in an analytical model that will increase the readers’ understanding.

5.4.1 Transformation, Flow and Value Conceptualization

Koskela et al. (2010) argue that both CC and LPS focus on the flow perspective, rather than the transformation perspective, where variations are neglected. CC and LPS emphasize the real flow of work, not just the order and timing of the tasks. However, they differ in the approach to secure a predictable flow. In CC, aggregated buffers and frequent reporting handles or mitigates variations and uncertainties in projects. The frequent reporting enables synchronization with other activities and resources. On the other hand, LPS seeks to reduce variations through reduction of waste, especially in the workflow between work processes. The waste elimination is realized by compressing lead-time, reducing variability, increasing flexibility and transparency, and simplifying the process (Koskela & Howell, 2002). In contrast, the flow conceptualization is not central to CPM, thus it is often poorly represented (Koskela et al., 2010). Removal of constraints are limited and not done systematically, i.e. control is performed afterwards (Kalsaas et al., 2014).

Although the flow perspective is central to both LPS and CC, tasks are the main elements and a hierarchical breakdown structure (WBS) is being used (Koskela & Howell, 2002), concordant with CPM. In contrast, the transformation concept is poorly represented in Scrum due to the fact that no WBS exists. All activities are orally described in the Daily Scrums just before they will be executed, thus making it difficult to plan in a traditional manner. However, the flow and value concepts are represented in many ways. Flow is conceptualized through the feedback cycles provided by the Daily Scrums and the monthly Sprint Planning, Review and Retrospective meetings. In addition, the self-organizing teams allow dense information flow among the participants. Furthermore, transparency is one of the main pillars in Scrum, thus supporting one of the main principles of flow. The value concept is explicitly provided by the Product Backlog, which is a prioritized list of customer requirements. Also, Scrum acknowledges that customers are in the process of constant sense-making in order to determine requirements. Thus, by including the customer regularly, effective sense-making may take place and is directly influencing the project. The Daily Scrum and the monthly meetings also ensure customer feedback, eliciting transparency, i.e. the customer ensures that the Scrum team understands their requirements correctly.

According to Koskela and Howell (2002) the value concept is less represented in LPS, as value is concerned with fulfilling customer requirements through elimination of value losses in the process. Yet, the value concept is supported indirectly by increasing production system capability, which may be defined as the capability to produce products when and as the customer requires them. This is in contrast to CPM, where the plan is static and planning is done by “higher management” (Kelley Jr & Walker, 1959), without the flexibility found in LPS. In CC, the value concept is indirectly supported through aggregation of buffers, with the result of reduced total project duration, i.e. reduction of waste (Rand, 2000).

5.4.2 Overall Project On-track Monitoring

The central notion in traditional planning methods is cost control in accordance with completed work, which is secured through a retrospective milestone tracking. In LPS, however, there is a weak link to the Master Schedule, which has been addressed as a problem for cost (Junior et al., 1998), quality, and progress tracking during the execution (Kalsaas & Sacks, 2011). Yet, the customer requires some form of overall project tracking. Arguably, the retrospective PPC metrics secures overall progress tracking in LPS. In CC, the overall progress is secured by frequent progress reporting and analyses of buffer consumption. Scrum secures progress tracking by summation of work remaining, which can be done at any point during the project execution.

5.4.3 Learning and Improvements

A main concern in all the inclusive methods is continuous improvement and learning. In CPM, learning is usually the basis for planning future projects or periods, i.e. lessons learned. However, LPS is based on extensive cooperation between different disciplines, and especially the reverse scheduling is known to produce “aha” experiences about cross-trade connections between the participants (Kalsaas, 2012). In addition, reasons for non-completion of planned tasks are analyzed using the PPC metrics, thus securing improvements to be implemented in future planning periods. Similarly, reasons for buffer usage are analyzed in CC, thus the learning process is somewhat equal in LPS and CC. In Scrum, all the Scrum Events foster collaboration and learning, which are implemented in future Sprints. Scrum asserts that knowledge comes from experience and decision-making based on what is known (Schwaber & Sutherland, 2013). This is in accordance with what Kalsaas (2012) found in a theoretical discussion about LPS, namely that knowledge and problem-solving develop gradually in learning processes based on experience. Thus, Scrum and LPS are concerned with the same kind of learning processes.

5.4.4 Coordination Arenas

In CPM, the plan acts only as guidance and the planning is not done in collaboration, because it is seen as a task for "higher management", or expert planners (Kalsaas et al., 2014). Thus, there are no specific arenas for coordination. However, the inclusive methods secure coordination arenas in their own way. In LPS, the Last Planner meetings and daily standup meetings are specifically designed to secure coordination. In CC, coordination is secured indirectly by the frequent progress reporting. Thus, variations in task durations are managed through synchronization with other activities and resources. All the Scrum Events are designed to foster collaboration and coordination. In addition, the feedback cycles ensure adaptions to customer requirement, which is a coordination issue.

5.4.5 Commitment and Transparency

In CC, the transparency is increased through the design of the activity chain, and commitment should be covered by the frequent reporting on projected time for completion, thus ensuring proactiveness. LPS aims to increase the commitment to perform the planned task through public promises, public task completion checks, and non-completion analyses (Koskela et al., 2010). The Scrum Events are specifically designed to increase transparency, which is one of the main pillars in Scrum, and commitment is secured by the self-organizing teams. In CPM, however, the plan does not promote commitment because there is no collaborative planning. Yet, the plan increase transparency by visualizing the sequence of the activities.

5.4.6 Prioritized Tasks

In CPM, the activities on the critical path are prioritized. Yet, the sequential ordering acts as guidance, thus changing requirements are not accounted for as the plan is static (Kelley Jr & Walker, 1959). In LPS, prioritized, sound tasks are chosen from the Workable Backlog and implemented in the Weekly Work Plan. CC allocates resources based on critical chain complete to buffer consumption ratio. In Scrum, prioritized tasks are chosen from the Product Backlog and implemented in the Sprint Backlog.

Based on the discussion above, we present a comprehensive comparison of traditional planning methods like CPM, and the more iterative models LPS, CC and Scrum, in Table 5.1.

Table 5.1: Comparison of traditional planning methods, LPS, Critical Chain and Scrum.

	Traditional Planning (CPM)	Last Planner System	Critical Chain	Scrum
Transformation	Yes, tasks are the central unit in CPM.	Yes, tasks are the central unit in LPS.	Yes, linked activities with allocated resources.	No, tasks are rarely defined.
Flow Control	Workflow control is not central to CPM. Control is often performed afterwards.	Yes, by reducing variability, thus increasing predictability of the plan.	Yes, by aggregating buffers and reporting frequently.	Yes, through daily and monthly feedback cycles, and self-organizing teams.
Customer Value	Indirectly, through fulfilling customer requirements.	Indirectly by optimizing production system capability.	Indirectly, by reducing project duration.	Yes, by utilizing a product backlog and customer involvement.
Overall Project On-track Monitoring	Yes, the basis of CPM is cost control through retrospective milestone tracking.	Weak link to master schedule. Yet, the retrospective PPC metrics are used for progress tracking.	Yes, by frequent progress tracking + buffer consumption ratio measurement.	Yes, through daily Scrums, increment freezes, Sprint Planning meetings and PPC.
Learning & Improvements	Lessons learned are usually the basis for the next planning period.	Yes, by continuous improvement.	Yes, by continuous improvement.	Yes, the Scrum Events foster learning to be implemented in future Sprints.
Coordination Arenas	Limited involvement due to expert planning (Kalsaas et al., 2014).	Yes, the LPS meetings for collaborative planning.	Indirectly, by frequent reporting and synchronization with other activities and resources.	Yes, through the daily Scrum meetings and monthly Sprint meetings.
Commitment & Transparency	No, the plan is made by expert planners. Yet, transparency is secured by visualizing all sequential tasks.	Yes, by eliciting promises in collaborative planning meetings and root-cause analyses for non-completion.	Yes, by frequent progress tracking and synchronization with other activities and resources.	Yes, commitment is secured through daily and monthly meetings, and the feedback cycles increase transparency.
Prioritized Tasks	Yes, the activities on the critical path, although they are static.	Yes, only sound tasks are chosen to the weekly work plan, and sequenced in the right order.	Yes, critical chain complete to buffer consumption ratio.	Yes, prioritized tasks are chosen from the Product Backlog to the Sprint Backlog.

6 NARROWING THE FIELD OF RESEARCH

So far, we have presented our methodological approach, FMC Technologies, a detailed case description and theories, methods and concepts applicable to our research. The constructive research approach utilized is concerned with the development of constructs, which are meant to improve the performance of the case being studied. In addition, defining a unit of analysis is central in case studies. Thus, the description of FMC and the PPM, as well as processes in the project execution were presented early. Further, the understanding of the organization gave invaluable input for defining a research area.

Through our exploratory study, we analyzed and described current planning and progress control methods, as well as the tools used: Eplan and the PPM tool. Consequently, we found that the planning and production control[12] of engineering activities in FMC could be strengthened. During the initial planning of engineering activities, there seems to be an insufficient emphasis on the importance of "doing it right the first time", resulting in inconsistent milestone dates, poor resource allocation and parallel activities with long durations. This is in accordance with frequently found problems in planning of design, namely deficient planning, poor communication, unbalanced resource allocations and lack of coordination (Freire & Alarcón, 2002; Sverlinger, 1996). In addition, the subsequent progress control fails to capture the actual progress of the project. Several informants confirmed that the planning and engineering control within the enterprise is poor, thus a change in the processes is needed to ensure increased predictability and quality of the deliverables. Inevitably, this led us to the research question presented:

How to increase predictability in complex engineering and fabrication projects?

In order to increase predictability of the engineering, we had to look into theories, methods and concepts concerned with the complexity surrounding planning and control of design and engineering activities. Due to the fact that traditional planning methods have proven insufficient for design and engineering activities, more iterative and inclusive methods are sought. Consequently, LPS, CC and Scrum bring interesting supplements to traditional methods, as summarized in Table 5.1. Against this background, we have developed a construct aimed at finding the right combination of methods in order to increase predictability in the project execution. The framework is presented in detail in the following chapter.

[12] Henceforth, production control is called engineering control to capture the essence of "production" in engineering.

7 DESIGN AND VERIFICATION OF A FRAMEWORK FOR PLANNING AND ENGINEERING CONTROL

In this chapter, we present a construct on how the initial planning and subsequent engineering control can be strengthened by adapting ideas from the Last Planner System, Critical Chain and Scrum. The main purpose is to increase predictability in the project execution phase in order to ensure on-time delivery of documentation and drawings, and consequently hardware. We propose changes to the initial planning to cope with the problems stated in the previous chapter, namely inconsistent ordering of milestones, poor resource allocation and parallel activities with long durations. We also discuss the process of monitoring the actual progress of the project. Further, changes to the engineering control are in place to increase soundness of the execution, to ensure a predictable workflow.

We divide the project execution phase into two phases: a design phase and a documentation and drawing phase, illustrated in Figure 7.1. Planning of the design phase serves as a challenging task as the design emerges through a complex process where solutions and activities evolve as the process progress. In other words, the design phase consists of reciprocal dependencies, which must be handled through mutual adjustment. On the contrary, it has been verified that the documentation and drawing phase may be structured sequentially as long as it is postponed until a complete 3D model is present. Consequently, defining milestones in the documentation and drawing phase can be done initially as the content is known, while the design phase must be planned in greater detail closer to the execution.

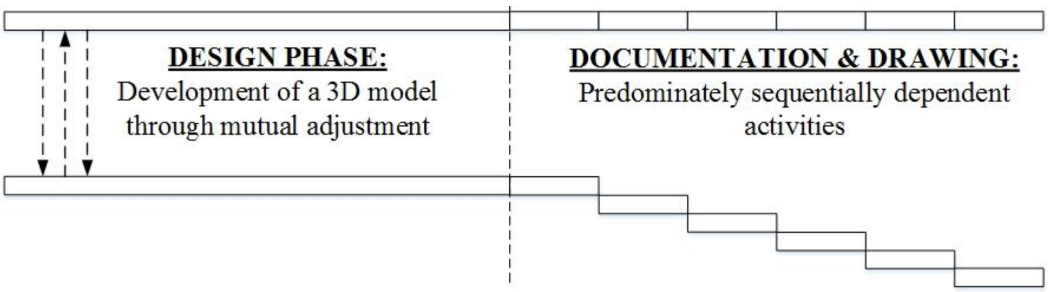

Figure 7.1: Division of the project execution phase.

The remainder of the chapter is structured as follows: firstly, we present a planning and engineering control framework for the documentation and drawing phase based on ideas from LPS and CC. The documentation and drawing phase is presented first to provide a greater overview before investigating the more complex design phase. Thus, in the first section, we treat design as an activity with a long duration. Secondly, we decompose the design phase and present a new way of structuring and controlling design activities based on ideas from Scrum and LPS. Finally, we summarize the construct.

7.1 THE DOCUMENTATION AND DRAWING PHASE

The documentation and drawing phase is hereafter called DR-4, cf. Section 3.2.3. In this section, we first present the initial planning, which is required to provide milestone dates of the engineering deliverables to the client. Thus, we discuss improvements of the initial planning, and provide a verification of the framework through a practical implementation in a given project. Secondly, we present the engineering control features of the framework, and discuss the practical implementation.

7.1.1 Initial Planning

The planning hierarchy presented in Section 4.1 will still serve as the basic hierarchical breakdown of plans. The top level of the planning hierarchy is the Project Plan, or Master Schedule. Utilization of Project Plans is central to traditional planning methods, LPS and Critical Chain in order to visualize the overall progress of the project execution. Project Plans are important for two reasons: firstly, the client demands it in order to get insight into the actual progress of the project. In addition, the Project Plan is often used to invoice the client, as FMC does. Secondly, the Project Plan serves as guidance for lower level plans (Koskela et al., 2010), as plans on lower levels often are divided into specific project phases or groups. Thus, the plan is often static and provides necessary milestone dates to different project groups or WPs, i.e. coordinates several disciplines.

Today, the Project Plan serves as a holistic milestone sheet in FMC, which provides input to the different Product Plans regarding delivery dates of the Scope of Supply. Milestones describe a condition or state that the project should reach by a certain point in time (Andersen, 1996). By using milestones, the plan can be read and understood without having detailed information about the underlying activities. Consequently, it can be called a logical plan because it shows the logical dependencies between project phases or disciplines. Thus, the synchronization between the different WPs is handled through the Project Plan, e.g. securing that products from the different WPs finish simultaneously for system testing.

Each WP has individual Product Plans, which are divided into additional milestones for each product and sub-assembly. These milestones are planned using reverse scheduling where lead-time on the activity, e.g. fabrication, serves as input, cf. Section 4.1. Thus, each sub-milestone in the Product Plan must be met in order to meet the final delivery of hardware. These milestones must be held static, in order to not interfere with the plan of other WPs, suppliers, fabrication, testing, etc. This is also in accordance with previous work presented by Kalsaas (2013), with a similar case enterprise, where it is suggested to differentiate the planning process of engineering and fabrication; delivery milestones from engineering are integrated into the Phase Plan of fabrication, and the engineering activities are navigated to meet these delivery deadlines.

One way of structuring the engineering activities, and consequently milestones, in the Product Plan is by adopting ideas from LPS alone. Yet, as discussed earlier, the actual progress tracking of the Master Schedule in LPS seems to be weak. Both Junior et al. (1998) and Kalsaas (2013) point out that there is a need to control actual progress in relation to overreaching milestones, and that some form of linear model should be used in addition to LPS. Thus, we seek to use elements from Critical Chain for this manner. This is in accordance with the suggestions of Shen and Chua (2008), who claim that CC can serve as a holistic management tool to control cost, progress, and quality. Accordingly, the Product Plan is structurally designed based on ideas from CC. Further, we need to rethink and strengthen the initial planning sessions to combat the issues regarding inconsistent ordering of milestones, poor resource allocation and parallel activities with long durations. Thus, we propose two ways to increase feasibility of the Product Plan and consequently the predictability of the execution:

- Collaborative planning: involvement of key personnel based on LPS.
- Buffer management and resource allocation based on Critical Chain.

7.1.1.1 Collaborative Planning

The initial planning of the Product Plans must be arranged as a workshop in the mobilization phase, where the PPM is responsible for conducting the meeting. The planning must be conducted in accordance with the Phase Scheduling in LPS. However, the planning period must cover the whole execution phase, in contrast to separate phases in LPS, to provide feasible delivery dates of engineering deliverables to the client. An important aspect in the initial planning is to include key personnel in order to collaborate on the reverse scheduling of all engineering activities, and secure that all activities and aspects are considered. Thus, a broader perspective can be achieved due to the participants' different backgrounds and experiences, compared to traditional planning by expert planners.

All deliverables are given document numbers and budgeted amount of hours during the tender, which serves as important input when executing the initial planning. The main concern of the workshop is to identify the right sequential ordering of the tasks, and evaluate their budgeted amount of hours. Bear in mind that activities in DR-4 can be considered "simple" when postponing the documentation until the design in DR-3 is made sound. Thus, all activities in DR-4 are mutually independent, while their sequence must be determined in relation to preceding activities in order to cope with the problems of inconsistent milestone dates. Furthermore, the evaluation of budgeted hours increases the feasibility of each activity.

To establish a proper sequential ordering of the activities, the Design Structure Matrix (DSM) might serve as guidance. By utilizing a DSM to evaluate dependencies between different activities, it is possible to elicit collaboration to identify input needed and output produced for each activity. Consequently, the sequential order of activities can be optimized. However, it can be argued that using documents and drawings as system elements in the DSM is insufficient. Hofgaard-Espeland and Høen (2012) found that documents and drawings as system elements did not capture the underlying decisions or activities necessary to produce the results. Furthermore, the quality aspect of the system elements is completely neglected before review. In our case, the former is secured through the postponement strategy. When DR-4 commences, underlying decisions to produce the results are already evaluated in the design phase. Further, they represent the deliverables in DR-4, thus their sequence become the vital factor. As such, documents and drawings can be considered sufficient system elements in FMC. Yet, it is important that the quality aspect is considered throughout the design phase.

As discussed initially, to plan right the first time it will be necessary to include key personnel. The PPM or Lead cannot predict all activities alone, nor can they easily discover tasks or activities with incorrect order. All team members have different backgrounds, experiences and agendas, which serve as important input when establishing the initial plan. The required participants are product and project specific. However, necessary Product Group leaders or division leaders, and appropriate engineers or senior engineers should be evaluated. In addition, the product planner must attend as technical support.

7.1.1.2 Buffer Management and Resource Allocation

When a proper sequential order is established, each activity may commence immediately after completion of the prior activity, provided all other required input is present. However, the soundness regarding resources could also be planned initially to strengthen the feasibility of the plan. Based on CC, resources must be allocated in advance to avoid parallel activities on individual resources. Consequently, the problem of infeasible resource allocations is reduced, while the visibility is increased. Whenever a resource is needed in parallel chains of activities, the activities must be sequenced in order to avoid parallel usage of resources, as explained in Section 5.3.2. An example is shown in Figure 7.2 where task A, B and C are sequentially independent in regards to prerequisite work, while the same resource are performing the work.

Figure 7.2: Sequencing of parallel activities (Leach, 1999, p. 45).

As Figure 7.2 illustrates, the duration of each activity is shortened due to fragmentation, although the budgeted amount of hours remains the same for task A, B and C, which will accommodate the problems of the Student Syndrome and Parkinson's Law. According to Leach (1999), a typical work pattern is similar to the graph in Figure 7.3. Leach claims that often less than one-third of the work is done within the first two-thirds of the period, resulting in extensive capacity usage at the end of the period. If it is not possible to recover the activity through added resources, the activity will be late and the participants will feel that the activity was underestimated to begin with. Meredith and Mantel Jr (2011) state that even though no empirical evidence exists for the Parkinson's Law, in their knowledge, anecdotal evidence supports this notion. As the graph in Figure 7.3 illustrates, work expands to fill the time allocated. Activities may require more time, but it will almost never require less. Thus, shortened activity durations may have several benefits.

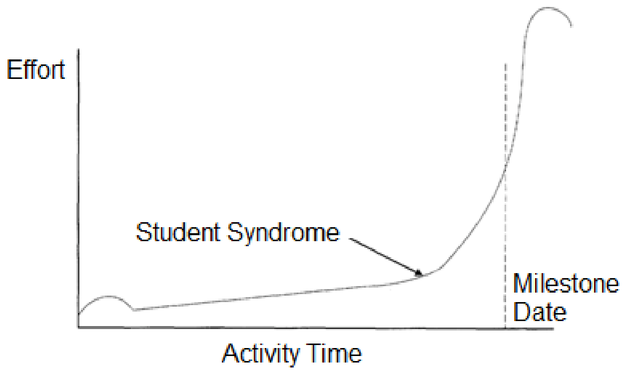

Figure 7.3: Effort over allocated activity time (Leach, 1999, p. 43).

In addition, with project specific resources allocated in accordance with CC, multitasking is avoided. Herroelen and Leus (2001) point out that multitasking is quite common in multi-project environments where resources often have more than one significant task running. However, such multitasking results in individuals who bounce back and forth, and may increase flow time of the individual activities. Yeo and Ning (2002) support this, and state that parallel tasks increase set-up time due to loss of concentration, especially when dealing with creative work. This is not the same as stating that each participant should carry out their work totally in sequence, because meetings and other tasks do occur. However, each participant should only have one significant task running during a particular time window, and complete her/his involvement in one project before moving on to another one. By doing so, work in progress will decrease, making progress more visible to other project participants, including management. Yet, multitasking may be optimal for some projects. For example, in R&D projects it might be more fruitful to share ideas and opportunities across several projects. McCollum and Sherman (1991) found such evidence by evaluating return on investment for long-term R&D projects, where the optimal solution was found to be two projects running simultaneously. However, in our study, the unit of analysis utilizes EPC projects where the main concern is to optimize current products to customer requirements. Thus, multitasking does not add value in our case.

As stated in Section 5.3.2, buffers should be used to mitigate the problems of "making do". In addition, by postponing buffers to the end of each activity chain, the duration of each task is shortened, which consequently cope with the problems of the Student Syndrome and Parkinson's Law. Thus, project buffers must be implemented at the end of several activities, rather than in the activity itself. However, the position must be evaluated for each part and sub-assembly based on the amount of hours needed, i.e. the "size" of the activity chain. The buffer could be added at the end of the chain for some connected deliverables in DR-4. Similarly, the buffers could be positioned at the end of all the engineering activities necessary "before PO", and at the end of the activities necessary to conduct "after PO", if the amount of deliverables are small and do not interrupt other milestones. Not only does the placement of buffers cope with the psychological aspect of the CC theory, it also highlights off-track activities. Whenever buffer capacity is used, the participants are notified that the activity, or the chain of activities, is off-track and that the delivery or future activities are threatened. The buffer consumption to completion ratio, as proposed in CC, could be implemented as a measurement tool. However, this has not been evaluated due to the challenges concerning a practical implementation in existing tools in FMC.

The buffer postponement requires a calculation of the buffer size based on the duration of the activity or activity chain. According to Raz, Barnes, and Dvir (2004), the CC framework does not provide any scientific or objective method for calculating buffer sizes. However, Tukel et al. (2006) point out several methods, where one in particular is more common in practice. The Cut and Paste Method is a simple method where all tasks shall be cut by 50 % in duration, and 50 % of this shall be added to a feeder or project buffer. However, Shen and Chua (2008) argue that this requires a project with extensive safety estimates in current activities. In the real-life of projects, this must be determined based on knowledge of the given tasks. They suggest that the soundness of tasks should be of guidance. When tasks are dependent on several inputs from preceding tasks, the probability of running late increases and the buffer dimension must be in accordance. In addition, Raz et al. (2004) criticize the buffer management of feeding buffers and claim that many projects begin with a few central activities, e.g. design, which are split into several parallel tracks (or feeding chains): leading to a complex network where the positioning of feeding buffers, or their necessity, might prove difficult to determine. However, as the Goldratt Institute recommends, the goal should not be to shorten the project duration, but rather finish on time (Rand, 2000), thus allowing some extra buffers. As such, it is not easy to give a clear method for sizing buffers in our thesis, but we do believe that the collaborative planning will provide sufficient experience in order to evaluate the buffer sizing.

It might seem time consuming to perform such detailed planning and structurally build a plan in accordance with CC initially. However, this level of detailed planning is actually done today, at least eventually, after the PPM tool is fed with information about resources and additional tasks. Yet, a template could serve as input to decrease the necessary time needed for the planning. As with the mobilization plan, a template could guide the PPMs with predefined activity links. Furthermore, experiences from previous projects could give more realistic input on the amount of hours needed for different activities, as well as input regarding buffer sizing. Yet, specific adjustments must be made for each project. This is supported by several of the informants, who state that it is possible to generate a generic plan, as long as project specific adjustments are considered. By utilizing templates, the duration of the initial planning workshop can be shortened. However, there is still a need for collaboration across different disciplines in order to increase feasibility of the plan.

7.1.1.3 Practical Verification of the Initial Planning

In order to prove the feasibility of the above presented framework for initial planning, similar planning was conducted for one of the products within the WAS scope. This section aims to describe the output from the process. In addition, several aspects will be exemplified to increase the understanding for later implementation. The result of the planning will not only serve as guidance for the given project, but can serve as a template for future projects with the same products in the scope. However, the planning was not conducted by the authors, but by internal resources with the aim of improving the initial planning of a newly started project. The chosen products were an “Emergency Disconnect Package” (EDP) and a “Lower Riser Package” (LRP), which are complex products within Well Intervention Products, or WP 25. Further, we are mainly concerned with the EDP to limit the complexity of explaining the template. The EDP is one of the most complex assemblies, and was chosen due to its relevance in most EPC projects containing a WAS scope. In Figure 7.4, a 3D model of the EDP is included to provide an understanding of its complexity.

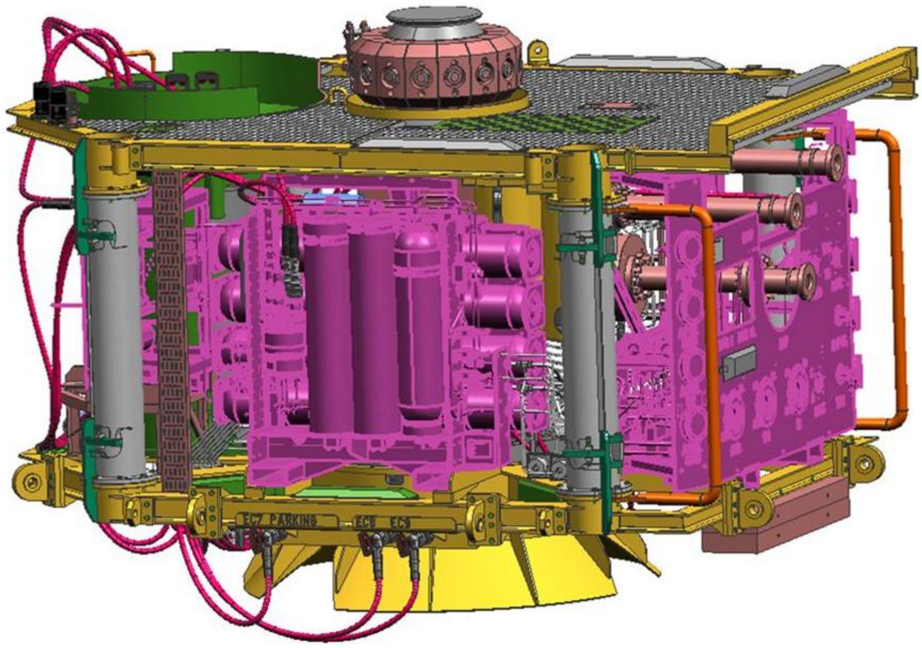

Figure 7.4: 3D model of the EDP.

Practitioners carried out the planning in collaboration as a workshop. Due to the high degree of knowledge of the product, e.g. by the product leader, a DSM was not used explicitly. However, such methods might be used to highlight dependency structures for practitioners with less experience. As described in Section 5.2, not only does the matrix sort out sequential dependencies, it also highlights reciprocal dependencies.

The result of the workshop was a rather complex chart containing over 100 activities in sequence. Resources were allocated in accordance with the presented framework, thus no resource was assigned more than 37.5 hours per week, and no tasks were put in parallel for the same resource. Each participant was then connected to one task at a time, and multitasking was avoided. Further, the workshop verified the possibility of postponing documentation and drawings until after the product design is fully completed. Prior to the workshop, the design and documentation were often conducted concurrently, leading to several parallel activities with long durations due to reciprocal dependencies between them. With several designers and engineers working in parallel, this often resulted in rework, i.e. negative iterations, due to late changes and poor communication. For example, 2D drawings were often made immediately after a section of the model was completed. Then, when adjustment was made to the initial section, all previously completed work needed rework in some sense. Thus, it is of great importance to freeze the design at some point, in order to make the DR-4 sound. The postponement strategy is shown for the two products EDP and LRP in Figure 7.5.

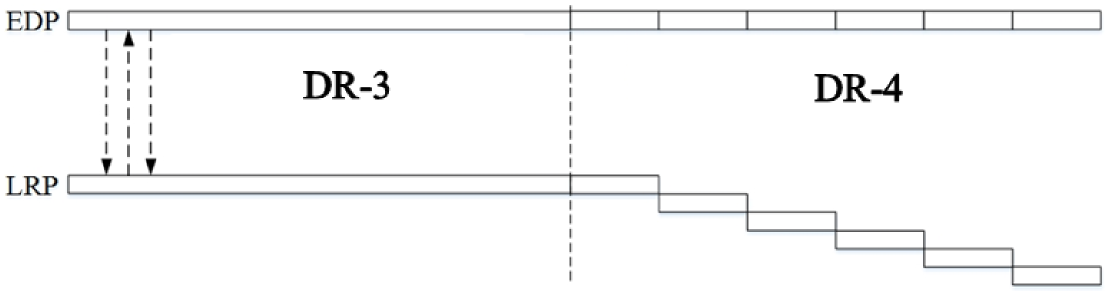

Figure 7.5: DR-3 and DR-4 for the EDP and LRP.

DR-3 is characterized by reciprocal dependencies related to other products, external interfaces and suppliers/workshop, which might influence the feasibility of a specific design. DR-4, however, is mainly concerned with making 2D drawings of the 3D model produced in DR-3, assembly and test documents, user documentation, etc. Thus, the documentation is postponed until all necessary information, i.e. the 3D models, are completed and approved.

During the workshop, the design phase was further divided into two activities or milestones, DR-3C (Concept) and DR-3P (Product), in relation to the design review process presented in Section 3.2.3. As seen in Figure 7.6, these activities expand over a long period: the total duration is approximately 6.5 months. Thus, these activities need to be further divided in order to ensure predictability in the design phase. The practitioners were not familiar with the term of reciprocal dependencies, and tasks within these periods had not been recognized. These phases were rather problematic for the practitioners, due to the iterative and inclusive way of working. Because of this, the activities got a milestone date and a rather long duration in order to conduct all necessary tasks. In addition, the phase was put in parallel with other products' design phases in order to develop the concepts gradually in collaboration. However, when we explained the limitations of sequential planning, the practitioners agreed upon finding a new way to plan and follow up on these activities. This is what Kalsaas and Sacks (2011) stated, namely that there is a need for better understanding of different types of dependencies and coordination methods. As such, ways to plan, coordinate, control progress and cost, and arenas for corrective actions in the design phase will be evaluated in Section 7.2.

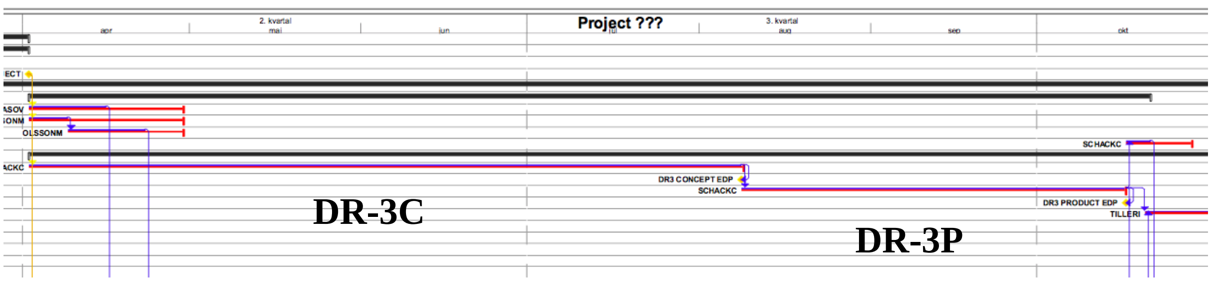

Figure 7.6: Output from the MS Project template for the design phase of the EDP.

After DR-3, enough information exists in order to complete the deliverables in DR-4. These are planned in sequence according to the information necessary to fulfill them, i.e. prerequisite tasks. An example is illustrated in Figure 7.7.

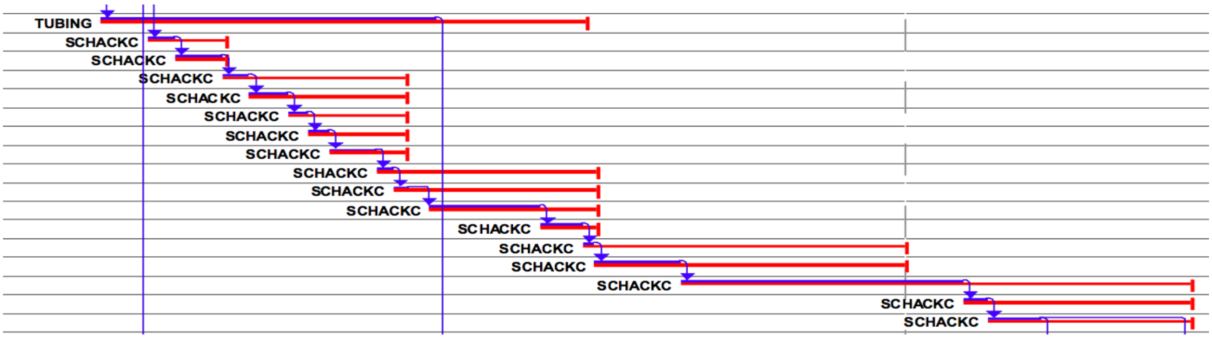

Figure 7.7: Decomposition of the DR-4 phase.

Since most tasks are dependent on input from DR-3 alone, these could in principle be carried out in parallel. However, since the same resource is completing them, the tasks are planned in sequence. Thus, the activity chain is in accordance with the CC framework. The blue bars represent the amount of work in hours and the real sequence of the tasks, while the red bars represent the milestone date that is provided to the client. Before delivery, an internal ECN review is held to check the quality of the deliverables. For time and cost reduction, several documents are gathered in these meetings. Thus, all the deliverables within one ECN release have the same delivery date, as shown in Figure 7.8.

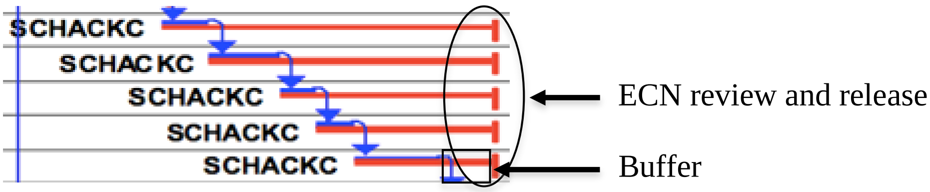

Figure 7.8: Activities planned in sequence with an equal ECN release date.

In addition, a small safety buffer is added prior to the ECN release. This is also in accordance with the CC framework, stating that buffers should be added at the end of each delivery chain. These buffers can handle small variations in the completion time without decreasing OTD. Further, any changes identified in the internal review might be done before delivery to the client. Based on previous experiences, it should be possible to foresee some regular issues, and thus size these buffers accordingly.

Even though these activities are planned in sequence, it does not matter which document or drawing are completed first or last as long as they are within the same ECN release. Thus, the sequential order is mainly used to smooth out the workload for the resource rather than giving strict instructions on what to do. However, to avoid multitasking it is recommended to start, work on, and complete one document or drawing at a time.

7.1.2 Engineering Control

As LPS demonstrates, planning is not only about the initial planning or doing it right the first time, it is also about production control[13], i.e. reduce variability and strengthen predictability in the execution. Generally speaking, traditional project management is about catching things after they have gone wrong, i.e. reactive, while LPS makes sure things can be done when they are planned, i.e. proactive (Mossman, 2013). Thus, the principles of production control from LPS should be implemented complimentary to CC for the initial planning, to allow more detailed handling of assignments, flows, and constraints (Shen & Chua, 2008). This is also supported by Koskela et al. (2010) who suggest weekly and daily planning across all tasks, as an extension of CC. However, we must first determine what tools to use for progress tracking in order to monitor the real-time performance of the project.

In the following subsections, we first discuss progress measuring in regards to the PPM tool, Eplan and the Product Plan, and conclude on how progress can be measured, both with regards to the tools used and the process of updating plans. Secondly, we discuss how activities and capacity can be aligned through forward-looking meetings to increase predictability in the execution.

7.1.2.1 Progress Measurement and Reporting

As a response to a request from FMC, and consequently the assessment in Section 4.2 and 4.3, we discuss how to measure earned value of work and actual usage of hours in accordance with the initial plans and budgets by utilizing the PPM tool, Eplan, the Product Plan or a combination of these.

After establishing the initial sequence of the engineering activities, these will be implemented in various plans and tools. Firstly, a discussion of the PPM tool is in place. By uploading activities into the PPM tool, a proper sequential order is established. However, the PPM tool is based on frequent updates, which now is structurally mitigated by the new planning framework. If we look at Figure 7.9, the frequent progress tracking is required because several activities are in parallel on individual resources. By distributing the activities according to CC, these are now sequentially planned. Consequently, the resource may complete one task at a time, thus the actual progress and usage of hours can be tracked accurately by simply knowing the status of the activity performed. In addition, the complete chain of activities visualizes the progress, and any buffer usage should highlight off-track

[13] Production control is monitoring of performance against project specifications (budget, plans, constraints, etc.) and corrective actions needed to conform performance to the specifications (Ballard & Howell, 1998).

activities. Thus, the PPM tool is now rendered unnecessary to estimate earned value of work or actual usage of hours, as the activity chain is sufficient for those estimates. Yet, some will still argue that the PPM tool includes activities not implemented in Eplan, like design review meetings or the 3D modelling. However, these could be included in the Product Plan, which will be discussed later in this section.

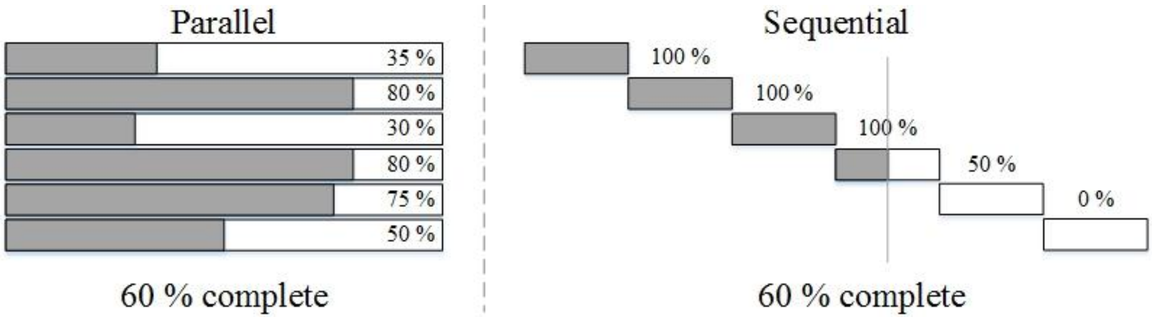

Figure 7.9: Progress tracking of parallel activities vs. sequential activities.

As stated, not all activities are fed to Eplan, only pure deliverables. However, as long as the collaborative planning is conducted and all dates are determined, it might be enough to feed the outcome into Eplan alone, especially since all engineering activities end up in a deliverable after the design phase. In addition, it is possible to extract an MS Project view from Eplan by using WBS codes to split up views in relation to Projects, WPs, Products, etc. This visualizes information of activities and delivery dates related to each product and sub-assembly. However, it is important that correct part numbers and WBS codes are fed into Eplan in order to use this function, yet such information seems to be incomplete when looking at current projects. In order to follow up with Eplan output alone, the project must be in accordance with the initial plan because Eplan does not link the different activities such as Primavera or MS Project. Consequently, if some activities slip, a VO or changes in the resource allocation occur, the other activities will not automatically be affected. In other words, the chain of activities can only be visualized by extracting an MS Project view, which is insufficient to analyze project impacts when changes occur.

Because Eplan is required for communication with the client, it will not be possible to use the Product Plan as a controlling feature alone. Thus, Eplan must be combined with either the PPM tool or a Product Plan. As the PPM tool is proven to be unnecessary, we need to discuss how the progress tracking with the Product Plan and Eplan can be performed in order to provide the best possible solution. The Product Plan contains milestones for different sub-assemblies and products, and must be aligned with Eplan. Today, the Product Plan is established using Primavera, which is similar to MS Project, although far more functionality is implemented in Primavera compared to MS Project. One benefit of aligning Eplan with the

Product Plan is visualization of changes to the plan. Thus, the plan can be updated if activities slip or a VO is requested in order to calculate the consequence on other product milestones and relocate activities. When the activities are relocated, it will be easier to update Eplan with new dates on all affected activities. In addition, activities currently not included in Eplan, like the 3D modelling, is implemented in the Product Plan. Thus, the combination of the Product Plan and Eplan effectively combat the argument that not all activities are implemented in Eplan. However, these activities must be weighted in the Product Plan. A downside with such extensive information in one plan is perhaps that the plan might be too complex and chaotic, especially if activities are rescheduled frequently. Changes do occur, and one idea of LPS is to plan in greater detail closer to the event and reduce variability by increasing the readiness of the task. As such, activities might be rescheduled before each sub-milestone in order to reduce waste in time spent on waiting for input due to incorrect sequencing. However, we believe that this should be handled in forward-looking meetings, and any rescheduling of the plan should be avoided in such detail. As long as the order of tasks does not interrupt any delivery milestones, the reordering could be a promise between the participants at the meeting, which is further discussed in the next section. Thus, the most promising solution would definitely be a combination of Eplan and the Product Plan, which render the PPM tool unnecessary.

When it comes to the process of measuring progress, all activities are implemented in the Product Plan. The progress of DR-4 deliverables is reported to the Document Controller, who updates Eplan. The Product Plan for each WP should then be able to get this information from Eplan automatically. The Project Plan is further updated based on the various Product Plans. The update of Eplan will be done more frequently compared to what was done prior to the PPM tool due to the sequencing of tasks. As soon as a deliverable is initiated (Start Prep.), or finished (Doc. Prepared), an update on status is sent to the Doc. Controller. However, the total amount of time spent on reporting is reduced compared to the amount necessary in the PPM tool. When the Product Plan is updated, the PPM can easily calculate remaining hours based on actual progress and hours spent. Consequently, EAC can be calculated and cost concerns will be revealed. Thus, the Product Plan serves as a linear tool to control progress and cost, in accordance with the addressed need of such system in LPS (Junior et al., 1998; Kalsaas, 2013). Further, the reliability of remaining hours is increased since each engineer is connected to only one task at a time. Thus, at the point of measure the engineers have completed some tasks, rather than nearly finished several. The latter can result in extensive work to finish the documents, because the remaining work is underestimated, thus resulting in increased EAC. As such, CC adds new ideas as a controlling feature, as proposed by Shen and Chua (2008).

7.1.2.2 Forward-Looking Meetings based on LPS

As understood by the Linguistic Action Perspective, mutual adjustment is a way of sharing learning and experiences between several disciplines, and commit to current demands. Thus, mutual adjustment has its benefits for reducing variability in execution, even though the tasks are carried out in sequence. Through LPS, this is secured in Lookahead meetings.

As an initiative to strengthen project management, forward-looking meetings[14] have been proposed by the FMC Management as an aspect of “Good to Great”. The basic function of a forward-looking meeting is to review the soundness of plans for the nearest future. In FMC, this will include the Project Plan and Product Plans, whereas a Phase Plan is reviewed in the Lookahead planning in LPS. However, the underlying principles are strikingly similar. FMC suggests these forward-looking meetings to evaluate critical milestones, while LPS seeks to align workflow and capacity, thus securing the reliability of plans. These forward-looking meetings are essential to ensure a predictable execution of activities in the nearest future.

The role of Lookahead planning in LPS (Ballard, 2000a) is a connection between the long-term planning, i.e. Master Schedule, and the commitment planning, i.e. Weekly Work Plans. However, if there is a gap between the long-term planning and short-term planning, the ability of the planning system to efficiently foresee the future is reduced (Hamzeh et al., 2008). Thus, forward-looking meetings will align the engineering activities with the delivery dates agreed upon with the client in a more efficient manner than experienced today. Several inputs are needed in order to execute engineering activities efficiently and successfully. Typically, information, prerequisite work, human resources, material (3D models, drawings, etc.), equipment (e.g. software) and funds must be in place (Koskela, 2000). Thus, to make sure these prerequisites are available and that planned workload is actually realized, actions can be taken in advance of the scheduled startup dates to make tasks ready for execution (Hamzeh et al., 2008). However, it is argued that the most challenging prerequisite for the sequential tasks in DR-4 is human resources. All necessary information can be found in the 3D models, which are a part of DR-3 and should be finished prior to the startup of DR-4. In addition, no limits in software or hardware for executing the activities in DR-4 are present since FMC provides a dedicated license and computer to each employee. The problem regarding resources is the difficulty of foreseeing the workload on each resource during the mobilization phase. Even though we suggest allocating resources in advance to secure proper workload distribution, a given resource might have been moved to another project, etc. In addition, the planned

[14] Further, the term forward-looking meetings are used instead of Lookahead meetings, in order to express ourselves in the terms adopted by FMC.

workload might change because of a VO, rework due to low quality of deliverables or underestimated budgeted hours. However, the sequential ordering of upcoming activities must be examined as well. Consequently, additional resources or a restructuring of the Product Plan are likely mitigating actions. Yet, it is important not to change the Product Plan too frequently, as it might be time consuming and ineffective to keep track on a constantly changing chain with a high detail level (Koskela et al., 2010). Thus, additional resources or reordering of activities should be agreed upon in the meeting and communicated to the affected engineers, without necessarily updating the plan.

If an activity exceeds the budgeted amount of hours or is late due to other disturbances, i.e. buffer capacity is used; reasons for non-completions should be evaluated and stored. This is important information in order to improve future projects. The information visualizes problems that are underestimated, e.g. resources being "borrowed" by other projects. Ballard (2000a) suggested some reasons for non-completion in the construction industry, as illustrated in the left column in Table 7.1. Other reasons will apply to FMC, especially when dealing with engineering activities. Some suggestions, based on previous discussions, are given in the right column in Table 7.1.

Table 7.1: Reasons for non-completion (Ballard, 2000a).

<table>
<tr><th>Construction</th><th>FMC</th></tr>
<tr><td>1. Lack of decision</td><td rowspan="2">1. Lack of prerequisites, if any other than resources</td></tr>
<tr><td>2. Lack of prerequisites</td></tr>
<tr><td>3. Lack of resources</td><td rowspan="2">2. Insufficient time, budgeted amount is infeasible</td></tr>
<tr><td>4. Priority change</td></tr>
<tr><td>5. Insufficient time</td><td>3. Late start</td></tr>
<tr><td>6. Late start</td><td rowspan="2">4. Conflicting demands, other projects consume time</td></tr>
<tr><td>7. Conflicting demands</td></tr>
<tr><td>8. Acts of God or the Devil</td><td rowspan="2">5. Project changes: additional work, VOs</td></tr>
<tr><td>9. Project changes</td></tr>
<tr><td>10. Other</td><td>6. Other</td></tr>
</table>

Most companies utilizing LPS, use a Lookahead Plan to foresee activities six weeks in advance (Hamzeh, Ballard, & Tommelein, 2012). In FMC, we believe the forward-looking meeting should span from six to eight weeks ahead, due to the fact that several deliverables are completed in sequence by the same resource before an internal review. Thus, the chain of activities spans over a longer period, and they are all concerned with the same prerequisite in order to be sound. The Lookahead meetings in LPS are commonly held once a week (Ballard, 1997). Likewise, a forward-looking meeting once a week in FMC would greatly improve alignment of activities and capacity, i.e. resources. Drawing on the ideas from Scrum, all meeting arenas should be time-boxed and standardized (Schwaber & Sutherland, 2013). Thus, the meetings should be held at the same time and location each week, and have a fixed duration and agenda. Consequently, the complexity will be reduced. However, the participants may vary according to the critical milestones ahead. First of all, the PPM will have a central role in the forward-looking meeting as he/she should have a comprehensive overview of the work package. Thus, the PPM should be responsible for arranging the meeting. The Lead engineer should frequently monitor actual progress and on-time completion by evaluating the Product Plan and must consequently attend the meeting. Evaluation of the Product Plan is invaluable input to the meeting in order to discuss hindrances in the workflow and reasons for non-completion. In addition, necessary Product Group leaders or division leaders must attend.

Any concerns regarding resources, whether the allocated resource is unavailable or the activity is underestimated regarding budgeted hours, must be reported by the Product Group leader or the division leader. Thus, we propose that each Product Group or division leader arrange a weekly meeting with their employees prior to the forward-looking meetings. Consequently, they will get updates on ongoing activities, input on the planned workload and commitment to upcoming activities through public promises, public checking of task status, and evaluation of reasons for non-completion (Koskela et al., 2010).

The forward-looking meetings should serve as a common platform for problem-solving through collaboration and sharing of information, knowledge and concerns. Critical milestones for the project and work packages should be examined, and collaboratively the participants must ensure that all necessary actions are initiated to meet the milestones. To ease the practical implementation at FMC, an agenda for the forward-looking meeting, based on the previous discussions, is provided:

- What activities are critical in order to meet the upcoming milestones?
    - Is the sequential order of the activities correct?
    - Is the resource allocation for the forward-looking window feasible?
        - If not, initiate mitigating actions to ensure feasible allocation, i.e. change requirements, add resources, etc.
    - Are all critical interfaces, i.e. milestones, to other WP’s / suppliers identified and correct?
- Examine reasons for non-completed activities
    - Employ a root-cause analysis
        - Ask “why” five times in a row to identify the root-cause.
        - Establish a library for root-causes.

7.2 THE DESIGN PHASE

By structuring the engineering activities in accordance with our proposed framework, the design phase becomes an activity with duration in excess of six months for some products. If we take the EDP as an example, the design phase is divided into DR-3C and DR-3P, see Figure 7.10. The DR-3C has a duration of four months and DR-3P's duration is two and a half months. Thus, the design phase becomes an extended activity, containing many reciprocal dependencies. However, to further strengthen the phase, existing problems are discussed.

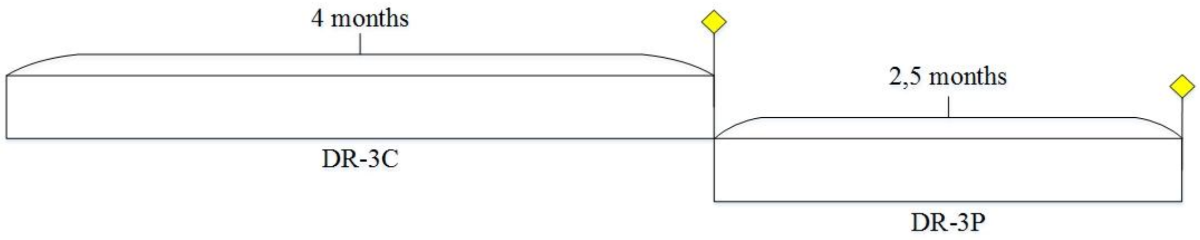

Figure 7.10: The design phase for the Emergency Disconnect Package.

As of today, the designers' work is often not structured; they just have to meet the milestones at the end of the design phase. However, it is not motivating to work on an activity with such a long duration, especially when each day is uncertain in terms of what to do and how to do it. In addition, the designers are required to update the PPM tool with progress daily. As one designer said, "it is not motivating to report one percent every other day, or seven hours a day when the total scope of work is 1.500 hours." Also, updating the PPM tool requires the designer to shift focus from 3D modelling to estimating hour consumption and progress. By doing this every day, it will add up to several hours over the whole scope of the design phase, which is wasteful in the sense that it do not add value to the product or customer.

In addition, there are concerns related to changes. For example, there have been large overruns due to insufficient cost and time estimates related to VOs from the client. When changes occur, and they inevitably will, there are no way of visualizing the impact a VO will have for the project in terms of cost and time. However, FMC must account for VOs, but not allow them to influence project delivery dates. Also, because there is no decomposition of the design phase, it is especially challenging to know where you are in terms of progress and how a change will impact your work. To illustrate this, we have included an example in Figure 7.11. When a VO is requested, the designer must determine how far he/she is in terms of progress of the design, and then estimate cost and time impacts related to the VO. However, without a decomposition, determining whether 60 % or 80 % is completed proves difficult. In addition, the designer does not know how the VO will affect completed work, i.e. does the VO affect the last 20 % or 40 % completed work.

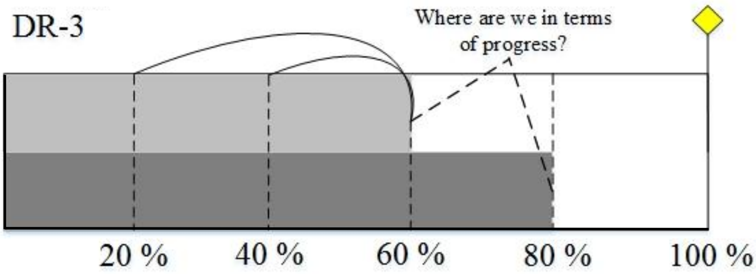

Figure 7.11: Example of issues concerning progress and impact of changes.

On the other hand, if we know that the VO will affect a single section of the design, which was completed at 20 % of the total scope, we can calculate cost and time related to rework of subsequent tasks. Other significant issues related to changes are internal disturbance. Today, there are no solely responsible for the 3D model. In other words, anyone can open the model and make changes to it. Inevitably, this leads to cycles of rework, known as negative iterations (Ballard, 2000b). Thus, to reduce the amount of iterations, a restructuring of the design process is required (Smith & Eppinger, 1997).

To accommodate the problems described, a new framework for the DR-3 phase is proposed. Our construct presents a new way of performing the work based on ideas from Scrum and LPS. Scrum has its roots in the software industry, i.e. concept development and iterative work, and LPS is mainly used in the construction industry. The remainder of the section is structured as follows: firstly, the idea of using Sprints to decompose the phase is presented. Secondly, we discuss how to organize the performing teams. Thirdly, the planning of Sprint Goals is evaluated, followed by a discussion of coordination arenas. We then present the utilization of a document to record the development of the design throughout DR-3. Finally, we discuss the potential advantages and drawbacks of the construct.

7.2.1 Sprints

Sprints are a major part of Scrum describing the phases in which the work is carried out, as discussed in Section 5.3.3. This is in many ways similar to the Phase Scheduling in LPS, where activities and their sequence are determined. Handoffs between trades are identified as a part of the process to determine the sequence. The Sprints can be considered as these handoffs, where the frozen increment serves as input for other products' designs. However, in LPS the tasks themselves are the central unit of analysis, but Scrum focus on the achievement, or goal, within the phase. Either way, the first step is to decompose the design phase into smaller problems (Eppinger, 1997), or Sprints. As illustrated in Figure 7.12, both the DR-3C and DR-3P will be sequenced into several Sprints. According to the Scrum framework, a Sprint should not be longer than one month, due to complexity (Schwaber & Sutherland, 2013). The outcome of a Sprint shall be a usable and potentially releasable product increment. In FMC, this will be related to either a part increment or an interface freeze. This will depend on the product and the project, but the idea is that a Sprint is equal to one deliverable, which is frozen and can be distributed to other designers for interface input. Since dealing with conceptual development, the idea of focusing on the goal, rather than the tasks would be preferable. This is in accordance with Andersen (1996), who states that a milestone describes what is to be done, but not the way it should be done, thus milestone planning promotes result-oriented thinking rather than activity-oriented thinking. It will also be easier for other project participants to understand the content of a goal, rather than understanding the content of specific design tasks. In addition, the designer can work more freely in terms of solving the problem. Consequently, this motivates the use of personal knowledge and expertise.

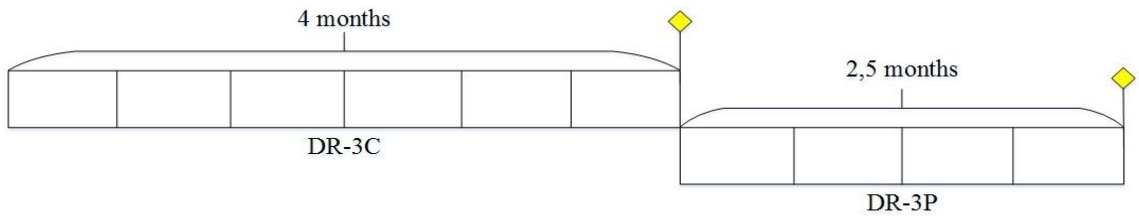

Figure 7.12: Decomposition of the design phase.

There are several advantages to dividing the design phase into Sprints. Firstly, the designers will be motivated when working against a smaller goal, within the near future. Secondly, the quality of the product, i.e. the degree of achieving the goal, can be checked and adjusted to avoid defects and shortcomings in the final delivery by involving the client, suppliers and workshop throughout the design phase (Male et al., 2007). Thirdly, the progress can be reported less frequently, and be more accurate since it is related to one increment of the total delivery. Finally, the transparency among other project participants and the client is increased by communicating in a common language. The latter is an important aspect of Scrum: a shared understanding of requirements and goals increase the visibility for non-experts, thus strengthening communication among all the involved parties (Schwaber & Sutherland, 2013). This may be a potential shortcoming of LPS in design, because focusing on tasks in the overall picture may cause communication problems.

7.2.2 Sprint Teams

In Scrum, development teams handle the Sprints (Schwaber & Sutherland, 2013). Different roles are gathered in self-organizing and multi-functional teams consisting of 3 - 9 members. The idea is to work in smaller teams on the same goal to maximize opportunities for feedback on the current situation. The whole team is working constantly on the same project, thus the projects must be small or divided into small pieces. For the latter, product increments can be shared as input to other development teams. The use of increments as handoffs is not explicitly described in the Scrum literature. However, the reason for using increments is to have a measurable deliverable for progress purposes, and for feedback from the client. If we mix the ideas of Scrum and LPS by using increments to secure proper handoffs, we would get a predictable flow of work for others since the input is frozen. In addition, feedback from the client, suppliers and other participants will be evaluated prior to the freeze.

In FMC, the Sprint Team[15] should consist of a designated designer and project engineer at the product level, as well as the Product Responsible Engineer. The division of teams should follow the breakdown structure used today within each Product Group, where products are separated. Each Scrum process[16] consists of several Sprints, as illustrated in Figure 7.12, and must be connected to one product and "owned" by one dedicated designer, and all changes have to go through him/her. However, several designers and engineers must work indirectly in the same Product Group where interfaces and concepts are evaluated in teams. As such, the design process of each product can be measured against predefined goals, while the different engineers can cooperate within each Sprint and give feedback before an increment freeze.

The self-organizing Sprint Team coordinates internally regarding tasks characterized with "team arrangement", the fourth interdependency presented by Van de Ven et al. (1976). This is a typical team workflow where the team collaborates jointly to execute the process and solve problems without lapse in the workflow, in contrast to reciprocally dependent tasks. The designer and the project engineer actually carry out their work in this manner today. They collaborate jointly on how specifications from the client can be implemented in the concept design. Thus, the coordination method is mutual adjustment as a group mode, where the task or group, i.e. Sprint Team, is in center and the coordination takes place through both unscheduled and scheduled meetings. When coordinating among other Sprint Teams, the client, workshop, etc., to get feedback prior to an increment freeze, the coordination method is in accordance with what Van de Ven et al. (1976) describe as mutual adjustment in a personal mode. Then, mutual adjustment is based on direct communication with other actors, either vertically in the hierarchy, i.e. superiors, or horizontally to other role actors. However, the Sprint Team is still in center, since the work within each Sprint is carried out as a team, rather than individually. The actual process of coordinating, both internally in the Sprint Team and among other participants, is further described in Section 7.2.4.

[15] We use the term Sprint team, rather than development team to differentiate from the Scrum framework.
[16] A Scrum process is equal to the DR-3 for one product.

Van de Ven et al. (1976) argue that when uncertainties of the task increase, a decrease in vertical communication and a significant increase in horizontal communication forms are found. This implies that when the tasks become more variable, as with concept development, adjustments are made among other role actors rather than superiors. This further supports the idea of having self-organized teams, which handle the development in the design phase for various products by mutual adjustment among other teams.

7.2.3 Planning of Sprint Goals and Increments

In Scrum, the goals within each Scrum process are planned in advance and filled in a Product Backlog. The Backlog is dynamic, containing the latest requirements, needs, enhancements, features, etc., and is used during the planning of each Sprint, i.e. the Sprint Planning. During the Sprint Planning, goals are chosen and prioritized, and activities and methods used to meet those goals are identified and planned in collaboration (Schwaber & Sutherland, 2013).

In our framework, however, the division of the total scope is carried out prior to DR-3 for each product. Thus, the Product Backlog is finalized and prioritized before DR-3 commences, and must be documented in the Design Review Minutes of Meeting (DRM)[17]. The reason for prioritizing the increments initially is to increase predictability and the likelihood of meeting the final milestone. In contrast, later prioritization makes it difficult to retain a holistic view.

Sprint Goals, i.e. increments, must be evaluated prior to the DR-3, as a collaborative process where the relevant Designer(s), Project Engineer(s), the Product Group Leader, and the Product Responsible Engineer attend. In addition, the Lead/PPM should evaluate the result. This process must be implemented in the Mobilization Plan Template for each WP in order to be fulfilled in due time. The process requires information from DR-2, and must commence at the end of the mobilization period. We suggest that the process should be added as an extra milestone prior to DR-3C, as illustrated in Figure 7.13.

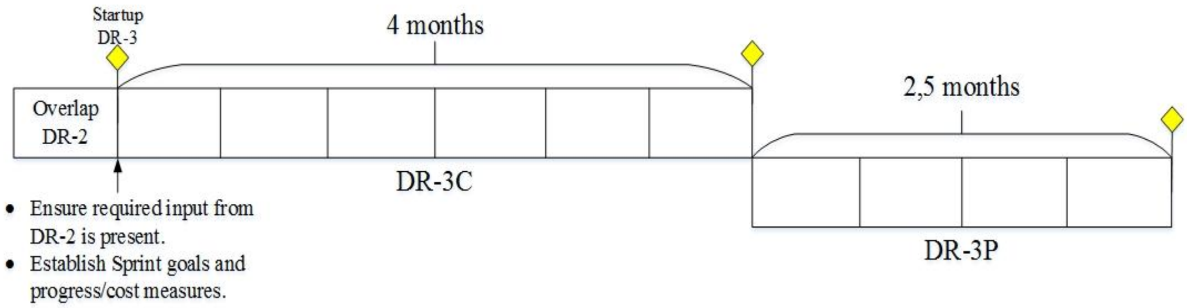

Figure 7.13: Enhanced decomposition of the design phase.

[17] Utilization of the DRM is described in detail in Section 7.2.5.

Input from DR-2 is often generic for each Product Group. Thus, it is important for each group to identify the needed information and make sure that it is made ready for DR-3 to commence. If the input is delayed, the Project must be notified in order to mitigate, and reduce idle time or waste. The general outcome of DR-2 is the following:

- Populated DR-2 Checklist (DRM10019099)
- Product Specification (SPC000000001)
- Electrical and Hydraulic Schematics
- Electrical and Hydraulic Analysis Report (RPT)
- Interface Documentation (SPC, DBD, LST, IDS)
- Outline Operations and Maintenance Manual (OMM)
- Modes of Operation (SPC)
- Design Basis for Analysis
- Outline ICP Plan (ICP)
- Master Equipment List (LST)
- Weld Procedure Index (LST000000001)

As an example, the Product Group of EDP/LRP need the following input in order to start; Product Specification, Electrical and Hydraulic Schematics/Analysis Report, and Design Basis for Analysis. Thus, it is important for EDP/LRP to follow up on these documents in order to make DR-3 sound, and secure necessary input for increment evaluation.

The total scope, all customer requirements, interfaces defined in the Systems Engineering, and internal interfaces must be evaluated for the specific project in order to define the goals and consequently the increments that shall be completed within the Sprints. However, generic Sprint Goals are difficult to determine. The reason is that the DR-3 is completely dependent on requirements from the client for the specific project. Typical project specific information is pressure load, water depth, the age of the field, limited installation space, etc. For example, there is less available information for a 30-year-old field than for a younger field, and limited installation space directly affects the outer dimensions of the product. In other projects, the product could be made out of a standard stack, requiring close to no time spent on the concept design phase, or DR-3C. However, two generic ways of defining increments were evaluated. The Sprint Goals should either be part increments, such as completion of different parts in the final Product assembly, or interface increments.

When utilizing part increments, each section of the product can be developed independently of other sections. A typical part increment for the EDP is shown in Figure 7.14, where the accumulator rack is highlighted. By knowing the connection fixtures at the frame and the limitation in outer dimensions, sufficient information is present for designing the rack. Thus, when the frame dimensions and connecting interfaces, such as the accumulator parking, are frozen, the accumulator rack Sprint may commence. The team must then gather new information to make the design complete, but this will not affect the previous work done on the EDP.

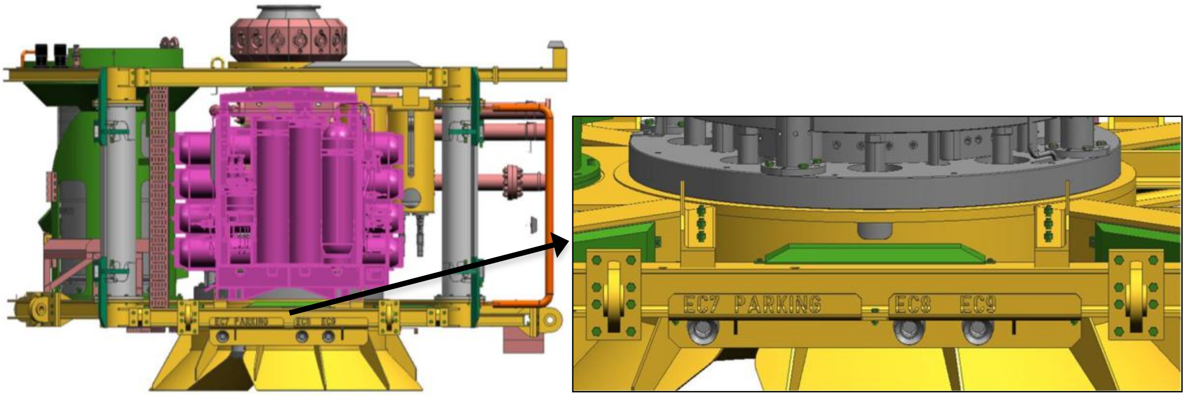

Figure 7.14: Part increment on the EDP.

Interface increments will be the proper goal if it is problematic to divide the Product into separate parts. For example, customer requirements might limit the height of the EDP, which requires parallel development of parts. However, one could define the Sprint Goals as internal or external interfaces, which serve as input for other designers. This is illustrated in Figure 7.15, where both the accumulator rack and the ROV panel are highlighted. Even though these must be designed in parallel, some interfaces might be locked, resulting in partly completed parts after each Sprint. When all interfaces are frozen, the model would be complete as well.

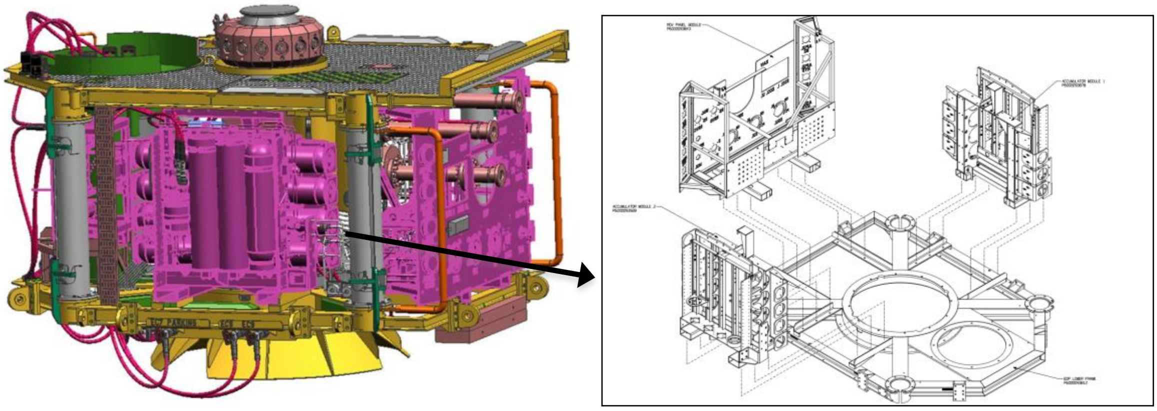

Figure 7.15: Interface increment on the EDP.

Further, the Sprint Goals must be evaluated in terms of their duration, cost and percentage progress in relation to the total scope. This information is then fed into the Product Plan, in order to follow up on progress and cost. Communicating these subjects will be easier with a predefined understanding. For example, the Lead is concerned with progress, the PPM is concerned with cost, the Product Group Leader is concerned with progress, resources and obstacles in the process, and the designer must indirectly report all of this. Thus, providing the involved parties with a common understanding of the Sprint Goal in terms of progress, simplifies the engineering control in the design phase.

For the EDP, in one particular project, one designer suggested the following part increments as Sprints:

- Startup – Sprint Goals are evaluated and frozen, DR-2 input checked: DR-3 made sound, and Composite Valve Block from Dunfermline evaluated: 10 %
- Sprint 1 – Accumulator rack design freeze: 25 %
- Sprint 2 – WOCM design freeze: 40 %
- Sprint 3 – ROV panel design freeze: 55 %
- Sprint 4 – Electric & hydraulic interfaces fixed: 70 %
- Sprint 5 – EDP frame design freeze: 80 %
- Sprint 6 – EDP top assembly design freeze: 100 %

However, since it is difficult to make a generic plan for DR-3 with predefined Sprint Goals, due to project specific requirements, the above presented example serves only as guidance for how part increments with progress measures can be implemented in the DRM for the EDP.

In Scrum, and in accordance with Lean principles, customer value is of great importance. This is achieved by having a dynamic relationship with the client, where the product is developed through Sprints, and where functions, features, etc. are added. However, in Subsea EPC Projects, the projects are basically managed with a Lump Sum. As such, any changes in the scope agreed upon shall be invoiced as VO. This is one of the reasons why the process described in our framework might seem a bit more static, compared to Scrum, when it comes to the initial planning of Sprint Goals and increments. However, when changes occur, and they eventually do, the framework has still several advantages, which will be further described in Section 7.2.6.

7.2.4 Meetings and Coordination Arenas

In addition to the proposed planning of Sprint Goals and increments, there is a need to discuss meeting and coordination arenas within the process more closely. The activities within one Sprint are characterized by reciprocal dependencies, since input and collaboration among other Sprint Teams, the client, suppliers, workshop, etc. is needed in order to complete the increment. Thus, mutual adjustment must be achieved in order to coordinate within the Sprint. Based on the ideas of Scrum and LPS, we discuss the following meetings:

- Forward-looking meetings
- Weekly meetings
- Daily meetings
- Retrospective meetings

Forward-looking meetings draw on ideas presented in Section 7.1.2.2, but is adjusted to fit the design phase and the Scrum framework. The meeting must be held prior to the startup of each new Sprint, and should be a mix between Lookahead planning from LPS and Sprint Planning from Scrum. In Lookahead planning, detailed methods for executing operations in the nearest future are planned. The activities in the Lookahead plan are evaluated in terms of soundness, and added to the Workable Backlog, if ready for execution. The Sprint Planning is also a collaborative process where a plan for the nearest future, the Sprint, is made. As previously described, the prioritization of Sprint Goals and increments is done initially, before the DR-3 commences. As such, the forward-looking meetings should only focus on how to meet the goal of the Sprint.

The Sprint Team should have proper knowledge to evaluate upcoming activities in order to achieve the Sprint Goal. The process could also be done in collaboration with other designers and engineers in the Product Group, as well as representatives from tubing, electrical distribution, manufacturers, workshop, etc. Information unfold when the project progress, and is based on the different disciplines in the project. As Macomber and Howell (2003) point out, it is of great importance for the project to use multiple sources, or participants, to unveil more accurate information. However, whether or not to use the time of other resources is project specific, and must be evaluated before each Sprint. The most important aspect is to identify any upcoming obstacles and mitigate these in order to make future tasks sound prior to commencement. Furthermore, the obstacles are added to an action list to keep track of the process. The action list can then be used as a dynamic tool to check if the tasks are completed. This list can in some ways be compared to the backlog in LPS. However, it is not a list of sound tasks, but a list of mitigating actions to ensure soundness of upcoming activities in the Sprint. The process of using the list is further described in Section 7.2.5. The constraints or preconditions in order to make upcoming tasks sound and achieve the Sprint Goal are mainly information and prerequisite work. The former might be specifications from the workshop, suppliers or client, while the latter might be internal information from other products' increment freezes. According to Koskela (2004), activities should not be started until all necessary inputs are available, in order to avoid the waste-generating mechanism of "making-do". However, as Kalsaas (2013) pointed out, "making-do" becomes a normal process of engineering design, because the initial information might be limited. When the maturity of the increment increases, so does the understanding of required information, thus the criteria for making future tasks sound must be adjusted accordingly.

The forward-looking meeting is not only for structuring work and highlighting potential problems in the workflow; it is also a meeting that distinguishes the different Sprints. It marks the transition into a new Sprint clearer, as a "kickoff", and should motivate the dedicated team when starting on a new increment. It is important that the previous increment is "done" and accepted by the whole team before the new Sprint commences. As such, forward-looking meetings should be held after the Retrospective meeting.

The Weekly meeting is more or less the same as the forward-looking meeting when it comes to the agenda. It is important to plan the future and evaluate status frequently, as the future is uncertain at the starting point of a Sprint, even though the Lookahead period is only one month or less. This is supported by Kalsaas (2013), who claims that the planning period must be shortened, and actions and decisions related to the actual engineering activities must be detailed on a rolling basis with a short-term perspective when dealing with engineering design. This is also in accordance with Ballard et al. (2009) who point out three main factors that distinguish production control during design: (1) uncertainty of ends and means, (2) the speed of execution, and (3) work complexity, which all are reducing our ability to foresee the sequence of future tasks. As a consequence, the rule to collaboratively plan in greater detail closer to the event still applies to design, but the forecast period is shortened (Ballard et al., 2009). Thus, it is important to make an arena for mutual adjustment, where potential problems or constraints can be identified and solved. Weekly updates would increase the likelihood of detecting potential hindrances in proper time without spending too much time in formal meetings. As one of the designers pointed out:

"It is difficult to arrange meetings with busy colleagues during the week. The Weekly meeting might just be such an arena, where it is possible to invite others into a discussion."

The Weekly meeting is not a part of the Scrum framework, nor directly related to the Weekly Work Plan in LPS. In LPS, a plan is made for upcoming feasible tasks. However, such is not needed since the Sprint Team carry out the work within the Sprint based on personal experience, and in accordance with the action list. In our framework, the weekly meetings are only held to secure more frequent Lookahead meetings for mutual adjustment, i.e. weekly Lookahead planning where the Sprint sets the limit. In addition, as discussed at the workshop, it will increase the possibility to collaborate on better solutions across several products, i.e. reduce the total time spent on conceptual design due to a common solution. Thus, reducing time spent on negative iteration (Ballard, 2000b).

The designer will be responsible for conducting the meeting and preparing an agenda with updates on the current situation. The attendees must be evaluated for each week and is completely dependent upon the situation. As such, it is not necessary for the Product Responsible Engineer to attend each week, neither is it necessary for any purchaser to attend prior to DR-3P, or manufacturer/workshop to attend after DR-3C, in most cases. However, by taking the EDP as a case, the following roles should be evaluated for each Weekly meeting:

- Project Engineer and Designer (mandatory)
- Project Engineers and Designers from other teams
- The Product Responsible Engineer
- Workshop / Assembly representatives (DR-3C)
- Manufacturer representatives (DR-3C)
- Tubing representatives
- Electrical distribution
- Purchaser (DR-3P)

Due to geographical distances, it might prove difficult to gather personnel like manufacturing representatives at these meetings. However, it is wise to have those in mind during the conceptual design. Our informants told us that much rework could be prevented if the concept was presented to the manufacturer at an early stage. If it proves difficult to arrange a meeting using conference equipment, the DRM could be sent for review. Even though the meeting is held to highlight and solve upcoming constraints for the product design, the Lead should attend occasionally. Firstly, it is important for the Lead to get a sense of actual progress within the Sprint, and assist if any hindrances disturb the workflow. Secondly, the Lead should help recognizing potential VOs. If there is a misunderstanding in requirements from the client and the designers add functions, it is important to have a “business” mind attending the meeting to invoice the client accordingly. If it is impossible for the Lead to attend, the Lead should spend time reviewing the DRM.

Scrum suggests to timeframe all meetings. However, the timeframe in our case will completely depend upon the Product Group, the Sprint Team, the need for assistance for Purchasers etc., and must be determined accordingly. Yet, the rule to arrange the meeting at the same place, at the same time, each week, will apply. This will reduce the complexity of the meeting, and contributes to a better information flow between the participants. In addition, shorter meetings should be held standing to avoid passivity, which may happen when using a meeting room.

According to the Scrum framework, daily meetings are used to coordinate within the development team, i.e. what we described as a Sprint Team. However, we believe that such formal meetings are unnecessary for FMC. The team could coordinate smaller issues and synchronize internally on a daily basis as long as they are located in the same area. This is actually working quite well today, and is a part of the team being self-govern. However, it was pointed out in one of our workshops that daily meetings might be preferable if new team members are mixed in order to remove any social barriers.

When the Sprint comes to an end, the increment must be checked against all interfering parts or systems. This will be done in the Retrospective meeting. However, when the increment is finalized, no new problems should unveil due to the implementation of weekly meetings. It is, however, of interest to arrange a formal meeting in order to spend sufficient time to document the increment. A description of the increment shall be implemented in a minutes of meeting to "freeze" the known outputs of it. This is the Design Review Minutes of Meeting (DRM), which exists today, but is barely used. It will be the designers' main responsibility to update the DRM, but the rest of the Sprint team must contribute. In addition, feedback from the Sprint should be implemented. The information may range between smaller problems to more serious design problems. These could serve as important input before starting on a new Sprint, e.g. problems with tools, relationships, or processes. The problems might also be of interest for others. When the increment is approved, the progress is reported back to the Product Planner in accordance with the predefined Sprint Goal. Further, when the PPM reports EAC to Project, he/her simply calculates an estimate based on the actual progress compared to actual usage of hours. With measurable increments, the current progress measures are far more reliable than the ones found in the PPM tool, thus increasing the predictability. An interesting area in Scrum is the Sprint Review and Sprint Retrospective meetings, which in many ways are similar to the proposed Retrospective meeting. However, they add an extra aspect of Customer Value through discussions of how to optimize value for the Customer. This is something FMC should consider, even though the two business areas, Subsea equipment and Software development, differ quite from each other. The output of any such consideration could serve as a potential VO, which might increase the total profit.

7.2.5 Design Review Minutes of Meeting

The design review minutes of meeting (DRM) is a live document, which records the design process from project startup to closeout. The purpose is to document discussions, conclusions and action items of any formal or informal meetings, such as technical discussions. In addition, the DRM should be used throughout the DR-3 to ensure that key requirements of the project have been addressed, and act as a guide to the project engineer and designer to incorporate these key requirements at the point of design. This in contrast to how the DRM is used today, namely as an appraisal checklist after the design is ready for approval, i.e. it should be used proactively rather than reactively. Thus, we propose extended use of a DRM in our construct to improve planning and engineering control in the design phase. For DR-3, the internal document DRM10019101 can be used as a template.

Establishing the DRM and action list

The DRM must be populated prior to commencement of DR-3C, i.e. during the overlap with DR-2. First, the overall project and DRM information must be filled in Table 7.2. In addition to populating the DRM, appropriate or required input from DR-2 must be identified and documented. Important input from DR-2 to consider is typically system schematics, product specification, interface documentation, hydraulic and electrical schematics and analysis reports, concept design calculations, and material selection and corrosion protection philosophy, cf. Section 7.2.3.

Table 7.2: Overall project and DRM information.

Concept DR-3 Meeting Date:	
Topic:	
Project Name:	
Project Code:	
Engineer Responsible:	
Relevant Sub-system DR-2 (if applicable):	
Reference Documents:	
Reference Drawings:	
Approval Status:	☐ Level 1: Approved ☐ Level 2: Approved provided comments are incorporated ☐ Level 3: Rejected

The DRM must be aligned with the meeting structure during the design process. In other words, every meeting, informal or formal, must be documented throughout the process. The first meeting to be conducted is the planning of the Sprints. In this meeting, all present information, e.g. documents and schematics, must be recorded, see Table 7.3 for an example.

Table 7.3: Example of present information.

PRESENT INFORMATION / INPUT, DATE: dd.mm.yyyy
• Populated DR-2 Checklist (DRM10019099)
• Electrical and Hydraulic Schematics
• Interface Documentation (SPC, DBD, LST, IDS)

Further, the increments that are chosen must be documented with goals, progress percentage, and the budgeted amount of hours, see Table 7.4 for an example.

Table 7.4: Example of Sprint Goals, percentage of total scope, and hour consumption.

SPRINT GOAL	PERCENTAGE OF TOTAL SCOPE	HOUR CONSUMPTION
Accumulator rack interface freeze	15 %	225 h
ROV panel interface freeze	30 %	225 h
…		

These Sprint Goals should be more detailed, but due to the fact that this must be decided during the startup of DR-3, we have provided a simplified solution. When the DRM has been populated with this information, it is ready for use. However, it is wise to establish an action list in Excel alongside the DRM, like the one in Table 7.5. The purpose of the action list is to highlight actions and changes to be incorporated in the design or documentation.

Table 7.5: Example action list.

#	COMMENTS	AUTHOR	RESPONSIBLE	TYPE	DUE DATE	ACTION TAKEN	RESOLUTION
1.1	Update abbreviation list	John Doe	Jane Doe	General	dd.mm.yyyy	Changed	Abbreviation list updated in latest version

The actions must be numbered according to the Sprint they have been identified in, as well as the actual number of actions, described in Figure 7.16.

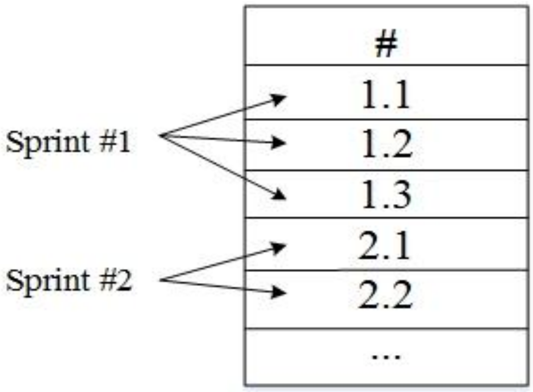

Figure 7.16: Action list numbering.

The “comments” field must be incorporated with the appropriate action, e.g. “Add: Special test equipment needed” or “Delete redundant table on Page 4”. The “author” is the person who identified the action, and the “responsible” is the person who should ensure the action is done by the due date. “Type” refers to the type of action; see Table 7.6 for appropriate type categories.

Table 7.6: Type categories.

TYPE
General
Grammar / Format
Add Clarity
Add / Remove Requirements
Add / Remove Content

The column for “Action Taken” depends on the type of action. For example, if the type is “add clarity”, the action taken is “clarified”, while “add/remove content” is often “changed”. See Table 7.7 for the appropriate categories.

Table 7.7: Action taken.

ACTION TAKEN
Changed
No Change
Outside of Scope
Clarified
Information Only

The column for “Resolution” describes the action taken in detail, if necessary. In addition, an action list color-coding could be of assistance, see Table 7.8.

Table 7.8: Action list color-coding.

	= Comments incorporated
	= Comments NOT incorporated or NO CHANGE required (see comments)
	= Comments outside of doc. scope and / or apply to another doc.
	= Clarification to author
	= Information Only

Sometimes, the actions discovered during DR-3, or especially at the Retrospective meeting, might be outside of the scope for the DRM. However, these actions could be necessary to implement in future projects. For example, the checklist currently in the DRM10019101 is quite extensive. Thus, if the action or request is to reduce the amount of checkpoints, it would probably be a valid request, but outside of the scope for this particular DRM. Proposed actions who are not incorporated are marked to visualize that the action has been considered, but not been incorporated.

Using the DRM and action list

The DRM should include sections for each Sprint, and all meetings during each Sprint must be recorded in it. By using the DRM in this way, it is possible to follow the progress of the 3D model from start to end. Currently, it is impossible to reverse the progress because the CAD tool utilized in FMC will only show the latest version. In other words, if the block you are working on starts out as a cube, but ends as a ball, there is no way to know how the block looked initially. Thus, we present how the DRM should be utilized in the different meeting arenas suggested in Section 7.2.4. First of all, a standard meeting label must be populated, like the one in Table 7.9, where the type of meeting, date and people present[18] are documented.

Table 7.9: Meeting label.

TYPE OF MEETING	Forward-looking / Weekly Meeting / Daily Meeting / Retrospective Meeting
DATE	DD.MM.YYYY
PEOPLE PRESENT:	

In the forward-looking meeting, the Sprint Team must evaluate upcoming activities, required information, constraints for removal and the Sprint Goal. Constraints or actions must be implemented in the action list with a dedicated responsible, due date and proper type category. The DRM should also refer to the action list with the actions found.

During the weekly meetings, the action list is still the main concern. The list must be updated prior to the meeting, and the participants must evaluate new constraints or actions. Old constraints must be further evaluated to keep continuity in the process of solving them. The DRM must be updated with reference to the actions discussed. Further, the designer must bring an updated 3D model or pictures of it into these meetings, to both update status and give the participants the possibility to provide feedback on the current situation. If necessary, these pictures could be added to the DRM under the right Sprint section with appropriate descriptions, to increase the traceability.

The daily meetings, which are not formal, and any other informal meetings arranged by the Sprint Team, could bring forward new action items. In addition, if any changes are to be done to the 3D model or the participants come to consensus on a subject, pictures of the 3D model or decision points must be implemented in the DRM.

The Retrospective meeting should be documented in the DRM with pictures of the 3D model at the end of each Sprint. The 3D model must be evaluated and accepted by the participants, in order to start a new Sprint. However, disputes on the 3D model, which must be cleared, can be added to the action list.

[18] Not all have to be present: input and information can be given in advance. However, being present enables two-way communication, which is preferred.

To illustrate the usage of the DRM, we provide an example using the EDP. During the first Sprint, the accumulator rack parking is set as the Sprint Goal. Thus, a picture of the completed parking should be implemented in the DRM, see Figure 7.17.

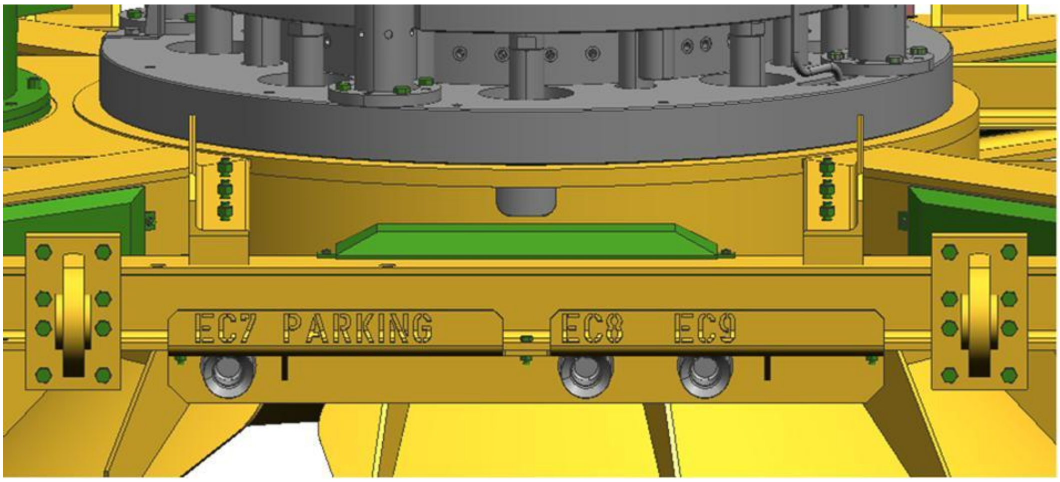

Figure 7.17: Accumulator rack parking freeze.

Further, the Sprint Team develops the accumulator rack, and by the end of Sprint #2, the rack is finalized. Thus, a new picture should be incorporated in the DRM, see Figure 7.18.

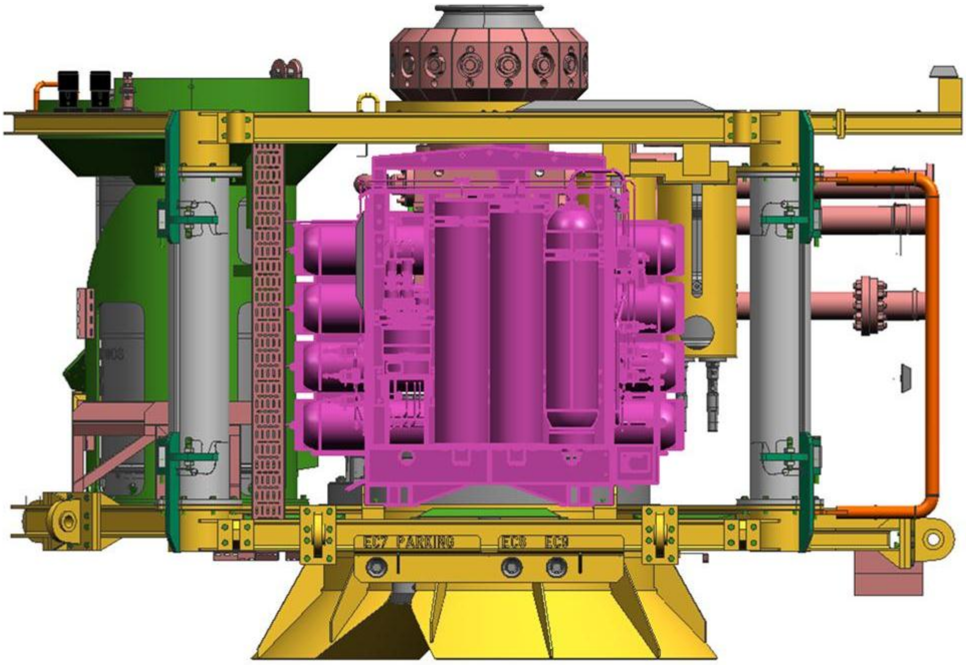

Figure 7.18: Accumulator rack design freeze.

However, if the client wants a different parking for the accumulator rack, the bolts connecting the accumulator rack to the parking has to be moved, e.g. 5 mm. Yet, by using the DRM, the team can simply backtrack and visualize that the VO will affect the accumulator rack as well as the parking. Thus, a more accurate estimate of time and cost can be sent to the client. In addition, the team can justify the estimates by sending the DRM.

7.2.6 Advantages

By implementing this new process, FMC will benefit in several areas. In this section, we will discuss the advantages of the new process in relation to the current situation. The proposed framework for the design phase is illustrated in Figure 7.19, where the current situation in FMC is at the top and our proposed construct is at the bottom.

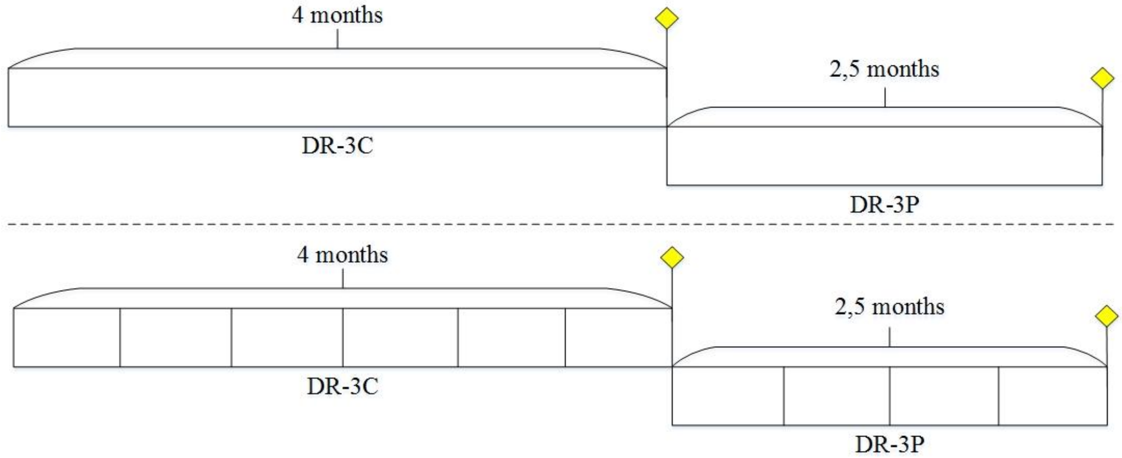

Figure 7.19: Current situation and proposed framework.

By dividing the design phase into smaller sub-problems, or minor milestones, increased predictability in the design phase can be achieved. Additional benefits are increased motivation, lower cost, and time and cost estimates that are more accurate.

Predictability in engineering is critical to meet the delivery date for the project. However, the way FMC manages the design phase today does not promote predictability. It is not difficult to plan an activity to last for four months, but to track progress and ensure on-time delivery of such an elongated activity is. Thus, by breaking the design phase into smaller activities, and deciding what input is needed, what the stage should contain, and what output will be produced, increased predictability can be achieved. In addition, we eliminate the problem of reporting progress each day, which currently force designers to shift focus from 3D modelling to cost and progress reporting. Of course, reporting is important and Critical Chain suggests that frequent reporting ensures predictability. However, reporting each day over a period of six months is wasteful, especially since it is difficult to track actual progress until the design is fully completed. Thus, the designer may concentrate on his/her main responsibility, i.e. 3D modelling, in order to actually meet the smaller milestones set within the design phase. Also, by ensuring that these minor milestones are met, there is a higher likelihood of meeting the major milestones.

In addition, by structuring the design phase, it becomes easier for the designer to know what to work on, what input he/she needs to secure, and how changes affect their scope of work. Furthermore, the scope of work in relation to the increment can be adjusted during collaborative meetings, and weekly meetings will ensure progress by identifying constraints for removal. Thus, the designer will be more proactive and motivated[19], which inevitably will increase predictability.

As mentioned, certain aspects of the new process will promote motivation. One designer pointed out that it is discouraging to initiate an activity with a duration in excess of six months, especially since it is difficult to know where to begin. However, by planning a sequential order of sub-milestones, it will be significantly easier to initiate the design phase. Also, milestones are great motivational goals, which reduce the effects of Student Syndrome and Parkinson's Law. Whereas a milestone six months ahead is discouraging, a milestone three weeks ahead forces designers to go at full thrust.

Lower cost is achieved by more accurate time and cost estimates when receiving a VO: thus, avoiding costly overruns. This new process will contain a set of increments, which visualize when different parts or interfaces have been finalized in the 3D model. In addition, reduced time spent on non-value adding activities, like frequent progress reporting, will also reduce cost. Consequently, the PPM tool becomes redundant because the designer, PPM and others, simply track progress in relation to milestones met, as opposed to reporting frequent progress on one design activity. By reducing the usage or removing the PPM tool, cost related to training of personnel, operation and maintenance of the tool could be reduced or eliminated. Furthermore, cost related to rework caused by changes to the 3D model done internally, will be reduced by not allowing anyone else than the assigned designer to make changes to the model.

Furthermore, this process will have great commercial value. Firstly, the entry point of VOs, and how they will affect subsequent work would be visualized. Thus, seemingly insignificant changes might have such an impact on the project that the client may withdraw the VO. Secondly, by visualizing how the VO will create rework on completed tasks, estimates that are more accurate can be achieved. For example, if the design phase is in Sprint #4 and receives a VO that requires changes to an increment from Sprint #2, you can trace how this change will affect the work done in Sprint #3 and #4. Thirdly, FMC can justify the cost and time estimates sent to the client.

[19] In our workshop 3. April 2014, a designer pointed out that their work is not structured at all. He would not know what he is supposed to do a particular day before reading his email inbox: consequently, he said a structured design phase would be more motivating.

7.2.7 Potential Drawbacks

Evaluation of Scrum-inspired processes from the software industry are often anecdotal experience reports, thus making it difficult to generalize the findings (Mann & Maurer, 2005). These experience reports are very specific to a company or environment, and do not contain enough context information to compare them to other reports. However, some research has been conducted to find quantitative results supporting the implementation of Scrum (e.g. Mahnic, 2011). One key finding in the research by Mahnic (2011), is that the initial estimates and plans when implementing Scrum tend to be over-optimistic. Yet, the estimates and plans improve over time. Mahnic (2011) gave 13 student teams an identical project to gather quantitative data on completion rate, and found that the completion rate during the first Sprint was only 42 % on average. However, during the second Sprint, the completion rate rose to 75 %, and by the end of the third Sprint, completion of planned tasks was approximately 92 % on average. Bear in mind that these student groups had no prior knowledge of Scrum, thus we expect to see a similar process within FMC, namely that completion of planned tasks will be low when first utilizing the framework, but the completion rate will increase with experience. In addition to over-optimistic estimates initially, there might be issues with introducing self-organizing teams, because the members may not have any prior experience with self-organizing or self-managing teams. Even though agile software development (like Scrum) emphasizes the need for teams to be self-managing, they offer little advice on how it should be achieved. This is supported by Moe, Dingsøyr, and Dybå (2010, p. 480) who states that:

"It is not sufficient to put individuals together in a group, tag them "self-managing", and expect that they will automatically know how to coordinate and work effectively."

In order to cope with this issue, trust and shared mental models seems to be of importance (Moe et al., 2010). Firstly, lack of trust may lead team members to expend more time and energy protecting, checking and inspecting each other as opposed to collaborate. In addition, team members may hold back information if they fear being perceived as incompetent. Secondly, without shared mental models, a key prerequisite for communication, monitoring and team orientation is missing. Consequently, team members may pursue individual goals instead of team goals. In our framework, this is sought mitigated through smaller teams. Furthermore, the team members are composed of personnel that cooperate on a daily basis today. However, in the case study by Moe et al. (2010), the employees of the company had been working together for years, but there still was a need to spend more time together focusing on teamwork in the initial phase of the project. Thus, we believe enough time should be spent initially to create a shared understanding of the goals and eventual product outcome.

7.3 SUMMARY OF THE CONSTRUCT

The proposed framework for planning and engineering control is quite extensive, thus a summary is provided. In addition, we revisit the analytical model presented in Section 5.4 to highlight the aspects of CC, LPS and Scrum, we have considered when developing our construct, as well as inequalities.

The most notable aspect of the framework is the division of a design phase (DR-3) and a phase where the deliverables are carried out (DR-4), as shown in Figure 7.20. By postponing the documentation and drawing phase until the design phase is fully completed, a great extent of rework is avoided. Thus, all required input will be present when any of the activities within DR-4 commence.

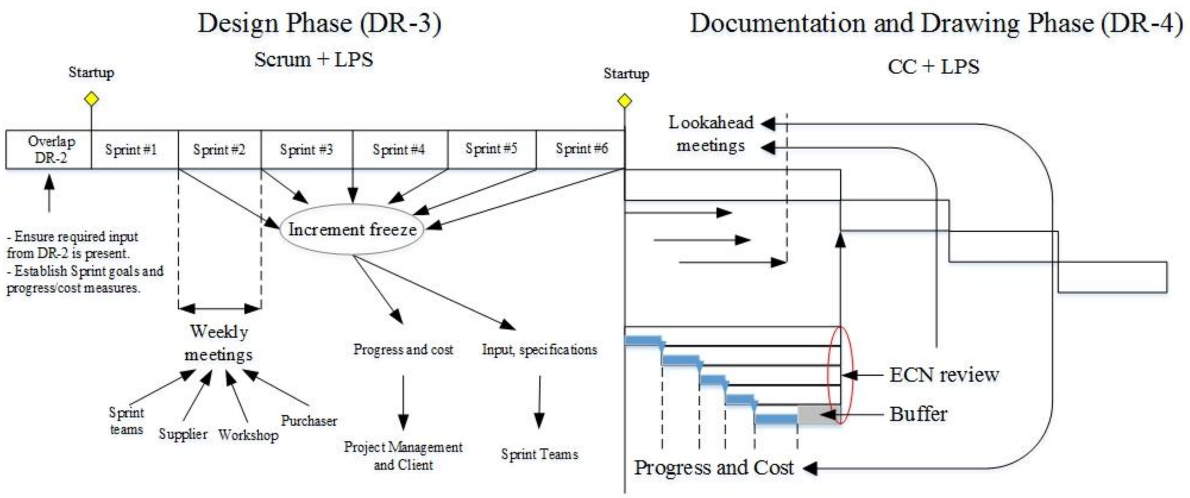

Figure 7.20: Illustrative model of the framework.

The design phase is divided into several Sprints, where the conceptual aspect of the product design is evaluated. The goals of these Sprints, or the increments to be completed, are determined upon startup of DR-3 as a collaborative process when necessary documentation from DR-2 is present. Cost and progress measures are determined in advance, and added to the Product Plan, which enables the Product Group leaders, PPM and Lead to track progress. The activities within the Sprints are performed by a dedicated self-organizing team for each product, working closely on a daily basis. Any concerns regarding other teams, possibilities for manufacturing or input from the workshop, are secured through weekly meetings where the current design is evaluated and any possible hindrances are discussed, i.e. mutual adjustment. These meetings and any decisions done during the Sprint are documented in the DRM in order to improve the transparency to other teams. In addition, any rework due to VOs can be calculated more precisely because the impact on previous designs, other products, WPs, etc. can be evaluated based on the DRM. Even though a comprehensive forward-looking meeting is proposed at the startup of each Sprint, these additional weekly meetings are necessary to plan in greater detail closer to the event. When the Sprint ends, a retrospective meeting is held to secure the completeness of the increment, and to evaluate "lessons learned", which is an important aspect of both LPS and Scrum. When the increment is completed, e.g. an interface, other products might proceed with their design. In addition to the formal meetings, informal meetings and discussions are held throughout the Sprint, depending upon the product and project.

When the DR-3 is finished, DR-4 commences. The activities within DR-4 are planned as a collaborative process with emphasis on the prioritization and order of the activities to meet the delivery dates of the hardware. Based on CC, resources are allocated in advance and the activities are sequenced in accordance with the resources, thus avoiding parallel activities on individual resources. In addition, a buffer is added at the end of each activity chain, e.g. before an internal review, to secure proper buffer management. Postponement of buffers mitigates the problems related to Parkinson's Law and the Student Syndrome, as does the sequencing of activities. In addition, by sequencing the workload for the participants, multitasking and frequent progress reporting is avoided. The latter was previously important for the PPM and Lead, in order to keep track of the various engineering activities. However, when the workload is sequenced, the activities become more visible and consequently easier to track. In order to increase predictability in the workflow, the ideas of Lookahead, or forward-looking meetings, from LPS is implemented. By evaluating constraints in the workflow in advance, proper actions can be taken prior to commencement, thus securing soundness of upcoming activities. Especially resources are of importance for these meetings, due to the fact that the projects span over longer periods, and the initial resource planning might have been affected by changes. In addition, rework due to VOs, poor quality, etc. might require additional resources due to increased workload. Reported progress, output from internal reviews, information from the engineers, etc. serves as input to these meetings. However, unlike the weekly meeting in the Sprints, these Lookahead meetings are held on a "higher" level, thus evaluating all ongoing activities within the whole WP scope.

The analytical model from Section 5.4 is presented in Table 7.10. All aspects of the different methods for planning and production control that were explicitly used in the presented framework is highlighted in green. A short discussion will follow.

Table 7.10: Comparison of traditional planning methods, LPS, Critical Chain and Scrum, revisited.

	Traditional Planning (CPM)	Last Planner System	Critical Chain	Scrum
Transformation	Yes, tasks are the central unit in CPM.	Yes, tasks are the central unit in LPS.	Yes, linked activities with allocated resources.	No, tasks are rarely defined.
Flow Control	Workflow control is not central to CPM. Control is often performed afterwards.	Yes, by reducing variability, thus increasing predictability of the plan.	Yes, by aggregating buffers ~~and reporting frequently.~~	Yes, through daily and monthly feedback cycles, and self-organizing teams.
Customer Value	Indirectly, through fulfilling customer requirements.	Indirectly by optimizing production system capability.	Indirectly, by reducing project duration.	Yes, by ~~utilizing a product backlog and~~ customer involvement.
Overall Project On-track Monitoring	Yes, the basis of CPM is cost control through retrospective milestone tracking.	Weak link to master schedule. Yet, the retrospective PPC metrics are used for progress tracking.	Yes, by frequent progress tracking + buffer consumption ratio measurement.	Yes, through daily Scrums, increment freezes, ~~Sprint Planning meetings~~ and PPC.
Learning & Improvements	Lessons learned are usually the basis for the next planning period.	Yes, by continuous improvement.	Yes, by continuous improvement.	Yes, the Scrum Events foster learning to be implemented in future Sprints.
Coordination Arenas	Limited involvement due to expert planning (Kalsaas et al., 2014).	Yes, the LPS meetings for collaborative planning.	Indirectly, by ~~frequent reporting and~~ synchronization with other activities and resources.	Yes, through the daily Scrum meetings and monthly Sprint meetings.
Commitment & Transparency	No, the plan is made by expert planners. Yet, transparency is secured by visualizing all sequential tasks.	Yes, by eliciting promises in collaborative planning meetings and root-cause analyses for non-completion.	Yes, by ~~frequent progress tracking and~~ synchronization with other activities and resources.	Yes, commitment is secured through daily and monthly meetings, and the feedback cycles increase transparency.
Prioritized Tasks	Yes, the activities on the critical path, although they are static.	Yes, only sound tasks are chosen ~~to the weekly work plan~~, and sequenced in the right order.	Yes, critical chain complete to buffer consumption ratio.	Yes, prioritized tasks are chosen ~~from the Product Backlog to the Sprint Backlog.~~

The transformation perspective is dependent on whether we discuss DR-3 or DR-4. For DR-4, activities, i.e. documents, are the central unit of analysis and the activities are prioritized in accordance with CC. For DR-3, however, the activities are not defined initially, only the goals, as proposed in the Scrum framework. Flow control is secured through forward-looking meetings, where the variability is mitigated through actions. Further, these meetings become arenas for mutual adjustment between different roles in both DR-3 and DR-4. This is what Scrum describes as feedback cycles, but mutual adjustment is also sought within the team through daily informal meetings. In addition, the buffers in DR-4 add visibility to the workflow. Whenever an activity chain is off-track, buffers are consumed, and the Product

Plan will visualize current activities consuming more than budgeted hours, which serves as input to the weekly meetings. Customer value is sought by optimizing the production system capability, which will result in increased OTD. Further, the value generation concept views design as a process where value for the customer is created through fulfillment of requirements. Thus, customer value is also optimized through the feedback cycles in the design phase, the DRM and involvement of the client, suppliers, workshop, etc. to secure a feasible design.

The progress is measured in retrospect, as proposed by all methods. However, the frequent progress tracking, as proposed in CC, is not adapted because it is more adequate to deliver a “done” increment in DR-3 and measure progress in relation to this specific goal. Further, the activities in DR-4 can be measured properly with emphasis on the due date because of their relatively short durations. Furthermore, adapting ideas from CC to the initial planning mitigates the weak link to the Master Schedule in LPS. Sprint planning is not done at startup of each Sprint, but at the startup of DR-3 to retain a holistic view.

Further, DR-3 adds the aspect of lessons learned which might serve as important input for future projects. The same goes for DR-4 with statistics of reasons for non-completion, reasons for variations, etc. Thus, the learning perspective is represented.

Proper coordination arenas for mutual adjustment are implemented in both DR-3 and DR-4 as discussed. In addition, collaborative planning is proposed to strengthen the initial planning and synchronize with other activities and resources. These coordination arenas are also important to increase commitment and transparency.

The sequence and content of the Sprints are planned initially. However, the Sprints are handled by the self-organizing team in DR-3. Thus, the team secures that pressing issues are mitigated throughout the process to secure a predictable workflow. In DR-4, mitigating actions are prioritized to secure the soundness of upcoming tasks. However, no Workable Backlog is implemented.

8 EVALUATION AND TESTING

As discussed in our methodology, constructive research is concerned with devising artifacts that can contribute to the theoretical field of research, as well as improving the performance of the case being studied. By discussing the construct throughout Chapter 7, we have verified its feasibility. Yet, the basic question remaining is "does it work?" Thus, a crucial component of the research is testing and evaluating of the constructs (Hevner, March, Park, & Ram, 2004). Firstly, we evaluate how problems found in our exploratory study regarding the initial planning and subsequent progress control can be mitigated through the new framework. Both the tools used, and the process of using them will be discussed for this matter. Secondly, we present a set of evaluation criteria and discuss how the construct relates to each of the criteria.

8.1 DISCUSSION OF THE PRACTICAL RELEVANCE

Since our study is concerned with finding ways of improving the performance at FMC, it is of great relevance to evaluate the framework in accordance with the problems presented in Section 4.3. We first discuss the problems with the initial planning, followed by a discussion of the problems related to progress tracking. Finally, we present the problems with the PPM tool and show how our construct mitigates those problems.

8.1.1 Problems regarding the Initial Planning

The problems regarding the initial planning are inconsistent sequencing of activities, poor resource allocation, and activities planned in parallel with long durations. However, the collaborative planning and the use of planning templates for input will strengthen the initial planning, thus increasing the possibility of "doing it right the first time". The same applies for the resources by utilizing proper resource allocation in advance. Also, the implementation of forward-looking meetings will secure the soundness of upcoming activities, in regards to resources and sequence. To reduce the amount of parallel activities, the framework proposes to postpone activities that can be sequenced, i.e. documentation and drawings. Activities that are carried out in loops with extensive use of mutual adjustment are handled in the design phase (DR-3), where increments are frozen through Sprints to reduce the amount of rework. In addition, the problems of multitasking, Student Syndrome and Parkinson's Law are structurally mitigated.

8.1.2 Problems regarding the Progress Tracking

The problems regarding progress tracking are related to the visibility of current progress and cost, and how this affects upcoming activities. By sequencing the tasks in accordance with the workload of the resources in DR-4 the transparency increases, thus avoiding the need for frequent progress reporting. Consequently, the PPM tool is rendered unnecessary. Further, EAC is calculated based on the progress reported in the Product Plan, in relation to hours used. For DR-3, the increments secure proper measurement points in the chain of activities. The increments can be expressed in a common language, which increases the visibility of this phase, and hence the predictability and likelihood of delivering on time.

8.1.3 The PPM Tool

As mentioned, the PPM tool proves unnecessary when extending the use of the Product Plan and Eplan. However, the tool was evaluated in terms of strengths and weaknesses during our exploratory study. Consequently, it is of interest to shortly discuss these in relation to the new way of managing the planning and engineering control. The strengths and weaknesses are repeated below, with the additional comments in italic:

- The problems of insufficient order of activities is improved in the PPM tool, since the tool separates "Before PO" and "After PO" activities, thus increasing the awareness when planning. *This is also managed through collaborative planning and by using templates as input.*
- The PPM tool includes several activities that are not part of Eplan, e.g. support activities. These are not a part of Eplan since Eplan is shared with the client for monitoring of deliverables. *These activities, like the design review meetings, are now a part of the Sprints, and included as milestones in the Product Plan.*
- The PPM tool encourages frequent status updates, which increase the awareness of each engineer, as well as commitment. However, the quality of the estimates is questioned. *Increments in DR-3 and initial sequencing in DR-4 increases the quality of the progress measurement. Commitment is secured through self-govern teams in DR-3, and inclusive forward-looking meetings in DR-4.*
- The PPM tool introduces a more progressive status tracking, compared to what Eplan offers. Thus, it is easier to track progress between "Doc. Prepared" and "Doc. Complete". This is a shortcoming in Eplan, because more comprehensive milestone reporting requires extensive communication with the Document Controller. *Frequent status reporting is avoided, thus Eplan becomes a sufficient tool for progress reporting.*
- The PPM tool requires less communication with the Document Controller since reporting is done individually. However, the fact that the tool is "open" requires some quality improvements. *Increased communication with the Doc. Controller is unnecessary due to less frequent status reporting. The quality of the estimates is increased by reporting completed increments.*
- The PPM tool offers a more comprehensive view of documents, drawings and other activities related to each part of the BoM structure, compared to Eplan. This makes it easier for each participant to analyze off-track impacts. In addition, the engineer will find relevant information

about the other participants. *The Product Plan and Eplan are now showing the sequence of activities and the performing engineer. Eplan may be structured according to WP, Product, Resource, etc. by using WBS codes.*

- The PPM tool is cost focused. Since resources are used in parallel activities, the estimates of remaining hours represent a cost issue, rather than a delivery issue. Further, it is impossible for the PPM to know whether the engineer will make it in time or not, unless the engineer flag his/her activity appropriately. *Parallel use of resources is avoided. The activity chain is made highly visible to increase the awareness. Further, forward-looking meetings secure proper management of variances.*
- The PPM tool has a major advantage with the PVO flagging. This enables communication between the project/contract engineer, and each participating engineer regarding any potential variation orders. This is not a function that can be easily implemented in Eplan. *The impact of VOs can be visualized through the DRM in DR-3, thus increasing the awareness. Then, potential VOs can be reported to the project and client for approval. In DR-4, forward-looking meetings within the Product Group secure communication with the participating engineers.*

Based on the discussion above, it seems that the new framework copes with the previously found problems, including the use of the PPM tool, which now may be removed due the lack of necessity.

8.2 EVALUATION CRITERIA

Hevner et al. (2004) propose five methods for evaluating constructs: observational, analytical, experimental, testing, and descriptive. Due to the limited time available, a descriptive method is the only appropriate in our research. Thus, we must perform an informed argument, or critical discussion, based on information from our knowledge base, i.e. the theories, methods and concepts presented, and other relevant research. According to S. T. March and Smith (1995), evaluation refers to the development of a set of criteria and the assessment of the construct against those criteria. A lack of criteria and failure to measure the construct performance result in an inability to effectively judge the research efforts. Evaluation of constructs tends to involve completeness, simplicity, elegance, understandability, and the ease of use. Thus, we evaluate both the report and the framework in accordance with the evaluation criteria suggested. However, the framework is a set of steps to perform goal-oriented activities, i.e. a “method” in the view of S. T. March and Smith (1995). Thus, the framework must be evaluated in terms of operationality, efficiency and generality as well.

8.2.1 Completeness

A construct is complete and effective if it satisfies the requirements and constraints of the problems it was meant to solve (Hevner et al., 2004). Regarding the framework, this has been sought out through the discussion of the practical relevance in Section 8.1. However, defining the requirements and constraints of the problem has been a comprehensive task. As discussed in the methodology, the process of finding the most promising area for improvement within FMC was challenging. Thus, our iterative approach may deem the construct incomplete. The reason why, is that if we had a clearly defined research area to begin with, a more in-depth analysis could have been achieved. In addition, what was unknown for us in the beginning is now known at the end of the research. Therefore, some aspects of the processes or organization that we now find second nature may not be present in the report in order for the readers to completely understand our inferences.

Furthermore, FMC is a large organization and it is impossible to get to know the whole organization and gather all the necessary information in the limited time available for our research. In addition, there is a cost issue related to the availability of informants. Consequently, the construct may be incomplete because of the limited time available for the employees to collaborate with us in finding the best solution for FMC.

We are also subject to bounded rationality (Simon, 1972), which is a limitation in our capacity to get and process all the required information, and to specify what information is needed and why. Consequently, information may have been filtered unconsciously. In addition, we are subject to the opinions and choices of the employees within FMC, especially of strong characters. However, we bring along an academic background for analyzing the case using well-known research methods, which may distance us from being governed too much by employees. In addition, our supervisors, both from the university and in FMC, have been guiding us throughout the research. As such, we believe we have presented a thorough and complete description of both the case and the proposed solutions, i.e. the constructs.

8.2.2 Simplicity

Another evaluation criterion is simplicity. Even though the organization, the processes in FMC and the research have been complex, we strive to present a simplistic representation of both FMC and the new framework. Yet, due to the amount of information and the length of the report, the simplicity may have degenerated. Firstly, all the information presented has seemed necessary at one point or another during our research, but may not seem important for the reader. In addition, some of the information herein will seem important to the employees at FMC, while the academics may not find it interesting, and vice versa. Thus, to please both worlds, we have included a comprehensive description of FMC, their project structure and processes, as well as a thorough literature review and proposed solutions to the problems. Thirdly, bounded rationality (Simon, 1972) may cloud our interpretation of what is necessary and why it is necessary. Consequently, the simplicity may not be as high as we initially wanted. Yet, the case description is based on numerous internal documents and informal meetings and discussions, and we have filtered the information into one comprehensive description. Until now, there has not been a single source of information like the one presented in our thesis, which will significantly simplify the process of understanding the project execution and processes within FMC.

In addition, we have striven to reduce the complexity when talking to employees by avoiding the use of foreign words. For example, words like Scrum, Sprints, reciprocal dependencies, etc. has not been used explicitly when discussing solutions with informants. However, we have described the content of these academic terms in more familiar words. For example, when describing the Scrum-based process for DR-3, we described it as a Stage Gate model, which is well-known in FMC. Each Sprint can be viewed as a Stage, while the Sprint Goal or product increments can be understood as a Gate. By doing this, we reduce the complexity and sources of error, e.g. misunderstandings. In addition, the employees talked more freely because they understood the questions we asked of them when using familiar terms. Yet, the academic terms are well-known within the research community. Consequently, we use those terms when describing the solutions in the thesis. Furthermore, the new framework is based on well-established methodologies and theories, which significantly reduces the complexity compared to constructing a completely new methodology or theory.

8.2.3 Understandability

The understandability refers to how easily the constructs are understood. In our opinion, understandability and simplicity are closely related. However, describing the case and our proposed solution as easily understood as possible has been quite complex. Consequently, when describing complex processes or methods, we have created numerous figures and provided simplistic examples throughout the report to promote the understandability. Yet, we know that the data and information presented might still seem complex to our readers.

8.2.4 Ease of Use

When evaluating the ease of use, we distinguish between the report and the framework. The report is divided into chapters and sections, thus providing easy overview and navigation. As such, the report is dynamic, i.e. we use cross-references to allow easy navigation to appropriate chapters, sections and figures. In addition, the case description is a single source of information combining data from several global and local work instructions, management databases and other archival records. Thus, if an employee is seeking a holistic understanding of the project execution, structure and processes, it is easier to use our report than to collect data for themselves from all the sources we have relied on.

The framework is developed with the existing structure in mind. Roles and responsibilities have not been changed. However, descriptions of new and old responsibilities are implemented, where new responsibilities are based on current roles. Furthermore, the new way of performing the work is developed based on the opinion of the different participants, such as Product Group leaders, designers, project engineers, etc. The sequencing of activities in DR-4 is supported by an example for two products, and is further backed-up through workshops. Thus, the implementation should be highly feasible. The same goes for DR-3, where the increments can be adjusted to the specific project. The authors would rather make a generic contribution, than a set of increments for one given project. Thus, we believe the ease of use is preserved through our adoption to the organizational structure.

8.2.5 Operationality

Operationality is the ability of humans to effectively use the constructs, thus highly linked to the ease of use. Since the framework is optimized to the current organizational structure in FMC, the implementation could be done quite rapidly. Furthermore, the ease of use and the simplicity of the report secure proper understanding for the implementation to be achieved. Any adjustments of the current framework may be done after the framework is fully implemented and when the proposed areas of measurements have been evaluated (e.g. reasons for non-completion).

8.2.6 Efficiency

Evaluating efficiency serves as a challenging task because efficiency cannot be evaluated completely without actually implementing the constructs and testing the results. Increased predictability is what it is all about, and to evaluate the efficiency of the constructs in regards to predictability, we need to see an increase in OTD of FMC’s deliverables. As mentioned earlier, approximately one third of all deliverables (excluding hardware) are on time, while two thirds are either late or has already missed the delivery date. Unfortunately, limited time available render us unable to follow through on the implementation and subsequent measurement of OTD. Thus, we recommend measuring the actual OTD by following the project over a period of time in future research. However, other areas of measurement should be evaluated in addition, since OTD is strongly affected by several factors. OTD may, however, show tendencies, which might support our research.

We also expect to see an increase in profit from the projects for two reasons: reduced cost and increased profit from VOs. Reduced cost is achieved by using less work hours on non-value adding activities, like the frequent progress reporting in the PPM tool. In addition, if the PPM tool is redundant, as we believe it is, cost related to training of personnel, maintenance and operation will be removed alongside the tool itself. Also, cost of rework due to changes in the 3D model done by others than the designer will be reduced by making the designer solely responsible for the model. Increased profit from VOs can be achieved by heightening the business awareness of engineers and designers, and by utilizing the DRM to record the progress of the 3D model. Thus, the designer can easily track the progress reversely if a VO occurs, in order to determine more accurate cost and time estimates.

Although we expect to see an increase in predictability and profit from projects within FMC, there is no way of knowing the exact efficiency without measuring elements or the economics of the projects in detail.

8.2.7 Elegance

Design, in all of its realizations (e.g. architecture, engineering, music, art), has style (Hevner et al., 2004). Given a problem and requirements for the solution, there is a degree of freedom in which the construct can be built in order to satisfy both the users and the researchers. Thus, Hevner et al. (2004) argue that the evaluation of a construct should include an assessment of the style, or elegance. However, measuring style is inevitably complex because style is subject to human perceptions and taste. Yet, Gelernter (1998) describes style as the union of power and simplicity. In other words, if the construct is both simple and efficient, the construct is also elegant. There is no need to discuss the elegance in detail. However, in the previous sections, we argued that the constructs are simple in the way that they provide dense information presented easily and understandably. Yet, we do not know to what extent our construct will prove efficient within FMC. As such, evaluating the construct in terms of elegance at this point of time is somewhat difficult. However, the combination of simplicity and efficiency will inevitably determine the elegance of our construct, possibly through future research.

8.2.8 Generality

Assessing the generality of the constructs is an important part of the constructive research design, because one goal of the research is to contribute to the theoretical background used in the research, not only improving the performance of the case being studied. For the most part, contribution to design theory and coordination theory will not be discussed. However, contributions to Scrum, LPS and CC are far more important in our research.

Scrum is an agile development process primarily used in the software development industry. However, the ideas from Scrum are very interesting when dealing with engineering design. In a way, software development and 3D modelling is similar. The product is developed through increments, and feedback from other actors is very important in order to produce a useable product with high customer value. On the other hand, LPS was developed to reduce variability and increase predictability in the Architecture, Engineering and Construction (AEC) industry. LPS has been developed throughout numerous conferences in the International Group of Lean Construction (IGLC) community, and is today a reputable framework. Koskela et al. (2010) claim that LPS has witnessed a rapid diffusion regarding its practical application. Further, they point out the rapid growth of Critical Chain, which now tends to be almost as popular in academia as the long existing Critical Path Method. However, as stated earlier, there seems to be a weak link to the Master Schedule in LPS. Furthermore, the application of LPS in design has been criticized. Thus, we believe the framework presented could be generalized in order to improve these areas of LPS. Due to the popularity of LPS, CC and Scrum, this should be of great interest for both academia and practitioners. As such, a paper to the annual IGLC conference has been developed simultaneously with our thesis. The paper is representing the thesis; however, the construct is presented in a more generic way, thus improving the generality of our research. Yet, the construct is very context specific and adjustments have to be implemented in order for the construct to be applied constructively in other industries and companies. This might a potential shortcoming for the generality of our construct, but by using well known theories and methodologies, which are applicable to a broader context, we prove the generality.

9 CONCLUSION

Increased predictability in design and engineering is what it is all about. Due to increased market competition, demands for efficiency, quality, safety and additional specifications, and severe financial impacts of delays, increasing the predictability and thus the likelihood of delivering on time is a critical element to remain competitive. After the quick growth in FMC, they now see that their competitiveness is challenged, which is the main reason for initiating the change initiative "Good to Great". One of the development areas is without a doubt the planning and engineering control, which is essential in order to understand how predictability in the execution phase can be increased. Thus, our thesis contributes to FMC as a case, but also in the broader perspective to understand how increased predictability can be achieved. In the following bullet points, we synthesize our contributions:

- A new understanding of problems related to traditional planning methods when dealing with design and engineering activities due to the iterative nature of such activities.
- A restructuring of the execution phase to ensure soundness and reduce the amount of negative iterations by postponing the production of documents and drawings until a complete 3D model is present, thus securing soundness of the information needed to produce the engineering deliverables. In addition, key informants and workshops have verified the need for a new way of conducting the initial planning and subsequent engineering control of the execution phase, as well as our contributions, which they believe will significantly ease the design and engineering processes. Thus, the verification from our informants is invaluable.
- A better understanding of different types of dependencies and coordination methods suitable to control the dependencies, which is in accordance with the need for such understanding presented by Kalsaas and Sacks (2011).
- A single source of information for project specific topics within FMC, which will significantly reduce the amount of hours related to looking up the information single-handedly, especially for new employees.
- Optimized engineering control through the development of current tools and techniques. We optimize the utilization of Eplan and the Product Plan by structurally mitigating the need for frequent progress reporting, which was the main reason for implementing the PPM tool. Thus, we reduce the necessity of the PPM tool, which inevitably will lead to more time spent on value-adding activities as opposed to non-value adding activities.
- A comprehensive construct to increase customer value by highlighting the impacts related to variation orders, which inevitably will increase profit and customer satisfaction.
- A contribution to the development of the Last Planner System, Critical Chain and Scrum by drawing on applicable elements of all to devise a construct. In addition, we developed a paper (Lia

et al., 2014) to the 22nd annual conference of the International Group for Lean Construction, which will bring our contributions to a broader research community. Especially, adding Critical Chain as a holistic management tool to the Last Planner System and Scrum to control the design phase is a pressing issue for the development of the Last Planner System.

There is no doubt that the increased demands for efficiency, quality, safety and additional product specifications will continue to rise in the future. In addition, market competition will increase, and to remain competitive is very challenging, especially in high-cost countries like Norway. Taking into account the costly overruns related to delays and deviations, and the ever-increasing race to accelerate production startup on new oil and gas fields, predictability is a very pressing issue for both FMC and their competitors. Thus, we have provided a construct that will help FMC highlight the need for a better understanding of predictability and how increased predictability can be achieved through collaboration, learning and continuous improvements. In addition, we see the potential for increased profit by reducing the amount of negative iterations, costs related to the PPM tool and improved accuracy of time and cost estimates related to variation orders. The construct is both informative and practical, and will serve as a common platform for sharing ideas and problems, which inevitably will lead to increased understanding and business awareness. To maintain the validity and reliability of our research, we have relied heavily on data, theory and methodological triangulation, and we have maintained a chain of evidence throughout the report to allow our readers to draw their own inferences and conclusions about our research. The validity is thought be solid, and reliability is thought be such that our findings can be generalized to other contexts and industries, at least to a certain degree. Yet, we acknowledge the need for adaptions and adjustments in order for the construct to be applied successfully and efficiently in other companies and industries. The construct has been verified throughout our research, and our informants believe it will significantly ease the design and engineering processes in FMC. In addition, the construct has been evaluated in terms of a set of criteria. However, we have not been able to fully investigate the efficiency of our construct due to the limited time available, thus we propose several areas for future research and improvements in the following section.

9.1 FUTURE RESEARCH

Even though our evaluation and testing proves the significance of the framework, for both FMC and academia, further research is necessary to enhance the framework after it has been implemented. Thus, the research areas are mainly concerned with the practical implementation and further development. Against this background, we provide several interesting improvement areas for future research:

- *Evaluation of reasons for non-completion, and consequently the effect on the predictability in engineering.* When an activity exceeds the budgeted amount of hours or is somehow late due to other disturbances, i.e. buffer capacity is used, various reasons for non-completions describe the phenomenon. The information might visualize problems that are underestimated, and by evaluating reasons for non-completion and analyzing activities that are running late, the framework could be further strengthened in order to increase the predictability of engineering tasks.
- *Evaluation of hindrances in the workflow of DR-4.* Even though the only prerequisites in order to complete the tasks in DR-4 is said to be resources, the 3D-model, and in some cases previously delivered documents, i.e. prerequisite work, monitoring of the process might unveil other forms of perquisites that are unknown. Based on the aspect of waste in workflow, new forms of hindrances are an interesting research area.
- *Evaluation of quality in the engineering deliverables, and its impact on the predictability.* Future theses should look into how often a deliverable is returned from the client and the reasons why. This could serve as important information in order to improve the quality aspect of the framework, thus reducing the amount of rework. By following a given project and documenting reasons for rejected documents and analyzing tendencies, an improved agenda for the forward-looking meetings could be of interest.
- *Implementation of Supplier documentation into the framework.* Our thesis is based on engineering tasks performed by FMC. However, some documentation is also made outside of the company, especially regarding “after PO” documentation, e.g. manufacturing documentation. It could be of interest to look into a possible adaption of external documentation control into the existing framework for internal engineering control.
- *Evaluate on-time delivery of engineering deliverables.* One of the aspects of predictability that we expect to see an increase in is on-time delivery of engineering deliverables. We encourage the researchers to follow a given project to analyze our construct in a project environment. This is especially interesting alongside one of the other topics presented above.

10 BIBLIOGRAPHY

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11 APPENDIX

Appendix 1: Interview Guide #1

Appendix 2: Interview Guide #2

Appendix 3: Workshop MoM

11.1 INTERVIEW GUIDE #1

Name	
Position	
Project	

The purpose of the interview

- Master's thesis in the last semester of our master's degree in Industrial Economics and Technology Management at the University of Agder.
    - How to increase efficiency of the PPM role?

Questions for the interviewee

- What are your responsibilities as a PPM?
- How are projects executed?
- What is the most challenging task?
- Whom should we talk to in order to get more information on that particular subject?

11.2 INTERVIEW GUIDE #2

The purpose of the interview

- Master's thesis in the last semester of our master's degree in Industrial Economics and Technology Management at the University of Agder.
    - Analyzing the way FMC plan and control production.
    - How to increase predictability of engineering deliverables in the project execution?

Questions for the interviewee

- How do you plan your work?
    - Primavera
    - Eplan
    - PPM tool
    - Excel sheets
    - MS Project
    - Other?
- What are the main problems with the initial planning, and how can these be mitigated?
- What tools do you use for progress tracking?
- Strengths and weaknesses with Eplan and the PPM tool

Strengths	**Weaknesses**

- What is your overall satisfaction with Eplan / PPM tool?
- What could be better with Eplan / PPM tool?
- Do you believe you need both Eplan and PPM tool?
- What are the main problems with the progress tracking today? How can these problems be mitigated in your opinion?

11.3 WORKSHOP MOM

Time and date: 03. April 2014 10:00-11.30.

Location: Gruve 90/3: Charlotte Amalie – 12 persons – Room 3333

Attendees:

Stefan Holmbom	Group Leader Well Integrity Products
Christoffer Schack	Design Engineer
Martin Lindblad	Senior Project Engineer
Børge Bjørnaas	Technical Training Manager – Global WAS
Knut Anders Lia	Researcher/Student
Henning Ringerike	Researcher/Student

Agenda: How to increase predictability in engineering?

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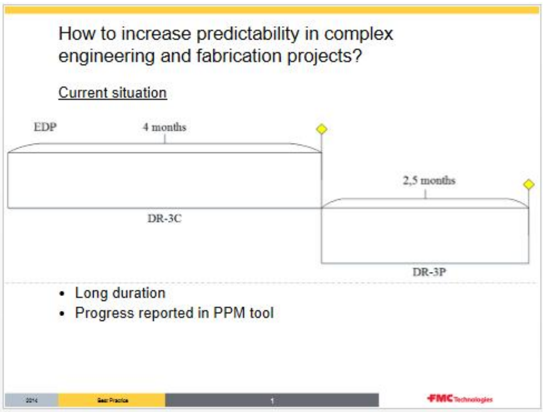

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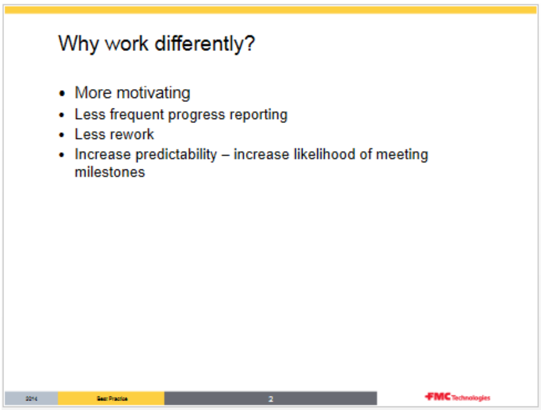

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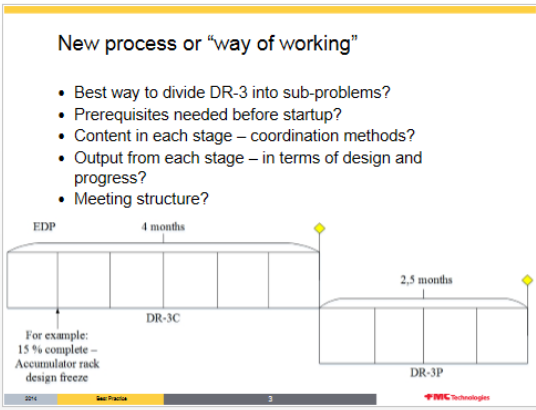

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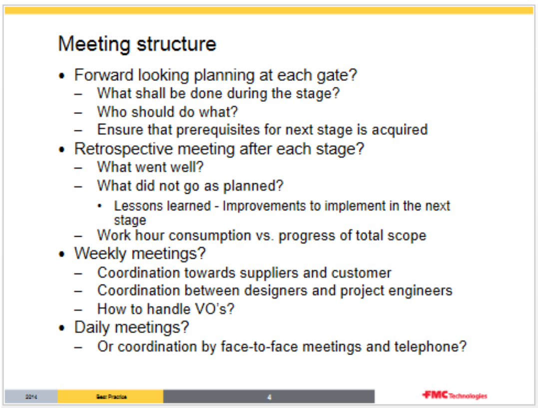

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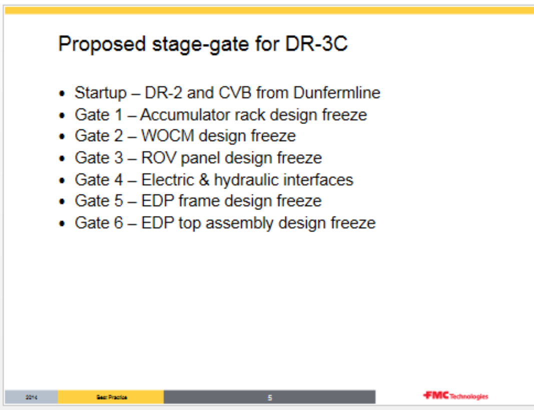

5

After our presentation, we opened for discussion. In the following section, notes and thoughts from the workshop are listed as bullet points.

Notes:

- Definition of interfaces should be done initially.
- The new process will be a great commercial tool:
    - Changes can be traced in terms of cost and time.
    - By utilizing a logical chain, change impact can be visualize for project participants and customer.
- The stages:
    - Startup – what is critical for this project?
        - Define needs from DR-2:
            - System schematics
            - External interfaces
            - Hydraulic and electric schematics
            - Hydraulic and electric analysis reports
            - Valve block (part of DR-3, but from Dunfermline)
                - Height?
                - Functions?
            - Design basis
    - “Gate 1”:
        - Set envelop
            - Set modules, sketches, upper and lower frame, guide posts.
        - Interfaces and envelope as gate
- Who should participate in meetings?
    - Lead, PPM, product leader/group leader, designers, project engineers, customer, supplier.
    - When to perform meetings? – Weekly.
- Use DRM as record book, as the MRB is used for manufacturing.
    - Upload photos of 3D models at each gate.
    - Align DRM with stage-gates.
    - Number system
    - Easy to distribute to others for communication with customer, and internally.
- New roles?
    - System designer/senior designer – one solely responsible designer (owner of the process). No one else should be allowed to make changes to the 3D model.
        - Problems with NX, backtracking.
        - Export step-file.
        - Flag consequences of changes
        - Read-only file for others
    - Should we merge project engineer and designer to one role?
        - Ideas from set-based design – downstream feedback, feasible solutions, etc.
- Make an new Local Work Instruction (LWI)
    - Explain our method and why they should bother using it
    - Explain advantages for engineers, PPM, designers
    - Explain time, cost and resource advantages
- Technical progress vs. cost/time progress
- Highlight idle time