INCREASE PREDICTABILITY IN COMPLEX ENGINEERING AND FABRICATION PROJECTS

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ABSTRACT

This paper addresses alternative measures to add to the Last Planner System[4] to increase predictability in the delivery of complex engineering and fabrication projects. Linear models have proven insufficient for planning and production control of design processes due to the iterative nature of design and engineering activities. In addition, practitioners have questioned the function of the Last Planner System in design. Thus, the purpose of the paper is to report research on the right combination of tools to increase predictability. The constructive research approach was used to analyze a case from the subsea oil and gas industry with low on-time delivery of documents and drawings. The construct divides the execution phase into a design phase and documentation and drawing phase. The design phase utilizes ideas from Scrum and the Last Planner System. Completion 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 Critical Chain and the Last Planner System. It has been verified that the division of the execution phase is a significant improvement within the case enterprise, and we seek to generalize the findings.

KEYWORDS

Design engineering, predictability, Last Planner, Scrum, Critical Chain

INTRODUCTION

Complex engineering and fabrication 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, improving predictability in the design process may reduce the risk of potential outburst from the initial budget. As the projects are increasingly becoming more complex, with both market competition and increased demand for efficiency, quality and specifications from the clients, design should be a priority. 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). However, due to the nature

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of the design process, planning serves as a challenging task. Traditionally, a lot of the planning strategies used for 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 at one time, and the entire set of activities converges to the design solution at once (Hoedemaker et al. 1999). Yet, 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 unnecessary iterations and rework, known as negative iterations[1] (Ballard 2000b), as well as time and cost penalties in both design and fabrication. Against this background, iterative and inclusive methods for planning design must be sought in order to improve predictability and quality of the deliverables.

Our purpose is to investigate a new way to perform the initial planning, as well as production control, based on the theories of Last Planner System (LPS), Scrum and Critical Chain (CC). A key success factor is involvement of key personnel, i.e. collaborative planning, in the mobilization phase of projects to ensure a feasible plan including milestones and allocation of resources. Project Managers, Lead engineers, and product group leaders must be part of this process to increase the quality and feasibility of the plan, allocate resources, sequence the workload, and commit to the plan. In addition, we look into current methods for progress tracking within the case enterprise.

In the following sections, we first describe the methodological approach to our research. We then briefly introduce principles and methods of different approaches for planning the design process. Next, the studied case from the subsea oil and gas industry is presented to illustrate applications of design planning approaches, followed by a presentation and verification of the new way of managing the design process, i.e. our construct. Finally, we provide a conclusion and propositions for further research.

METHODOLOGY

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. In addition, constructive research relates to design science research, which according to Simon (1996) is concerned with devising artifacts, e.g. tools, techniques, materials, and sources of power, 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 two of the authors have been working closely with the case enterprise.

To maintain the construct validity of the paper we have relied on the multiple sources of evidence (Yin 2009). The initial phase of the research was conducted as an exploratory study. The goal of the exploratory phase was to gain a comprehensive understanding of planning tools and techniques, as well as ways of leading today. This was achieved through reviews of internal documentation and informal meetings

[1] Non-value generating activities also referred to as waste in design.

and discussions with employees at different levels of the organization. Further, we conducted structured workshops with key personnel. The purpose was to discuss new ways of managing the design process and engineering activities to ensure improved predictability and quality in the execution phase of the project. Based on feedback from the workshops, our construct was adapted to better suit the case enterprise in order to increase the likelihood of a successful implementation.

DIFFERENT APPROACHES TO PLAN AND CONTROL ENGINEERING ACTIVITIES

The Last Planner System (LPS) provide an alternative to the traditional project management way of thinking. LPS was developed in order to reduce the negative impacts of variability and increase the reliability of workflow in construction (Ballard 2000a). LPS is not only a planning methodology, but also a production control framework. LPS has been thoroughly described in previous work by Ballard (2000a), as well as numerous papers presented at the IGLC[1] conferences. Thus, only the main principles will be presented here:

- 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.

Several papers have been presented on the subject of LPS in design (e.g. Ballard et al. 2009; Hamzeh et al. 2009; Kalsaas 2013). According to Ballard et al. (2009) there are three main factors that distinguish production control during design: uncertainty of ends and means, the speed of execution, and work complexity. Consequently, the rule to collaboratively plan in greater detail closer to the event still applies for design, but the forecast period is shortened (Ballard et al. 2009). Since design emerge through a complex process, we cannot fully predict the sequence of work initially, because new unforeseen design activities might be unveiled. Ballard (1999) argues that design criteria and solutions evolve as the process progresses, which is what Thompson (1967/2003) describes as reciprocal dependencies: relationships where output from one activity determines the next. Reciprocal dependencies must be coordinated by mutual adjustment, as found in the phase planning, lookahead planning and weekly work planning of LPS (Kalsaas & Sacks 2011). However, Ballard et al. (2009) argue that there still is a need for a detailed[2] master schedule at the beginning of a project to explore risks and exploit opportunities. They also point out that the assignment and execution should be done with multi-disciplinary teams in iterations. According to the Scrum framework, which is used to develop and sustain complex products, while

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[2] The level of detail may be discussed as the future is unpredictable, i.e. variances and uncertainties do occur.

delivering the highest possible customer value (Schwaber & Sutherland 2013). 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 competencies needed to accomplish their work. The team model is designed to optimize flexibility, creativity and productivity, while employing an iterative, incremental approach to optimize predictability and control risk. In Scrum, Sprints describes the phases in which the work is carried out. Each Sprint results in an increment of the total scope, which are considered “done” and potentially usable.

Kalsaas (2013) argues that LPS inspired techniques need a linear method for cost, quality and progress control, in order to deal with tracking on actual performance in relation to delivery dates and overarching milestones. In addition, the customer often requires such information. Furthermore, Junior et al. (1998) argue that it is difficult to measure status on site in accordance to the master plan by utilizing LPS only. Several methods might be used, but the authors would like to consider the Critical Chain Project Management (CC) theory (Goldratt 1997). CC is an adoption of the Theory of Constraints, both originated from Goldratt (1997). The adaption is based on the ideas of a holistic view, as well as management of constraints (Rand 2000). CC is in many ways a linear scheduling tool, considering the use of resources (Goldratt 1997). The Critical Chain is built by connected activities, where buffers are moved at the end of each chain, thus making each activity duration shorter (Stratton 2009). Parallel tasks in terms of resources are avoided, thus making the activity chain longer than traditional CPM. In addition, Feeding Buffers are used to secure soundness of non-critical tasks, in relation to the critical chain. A comparison of CPM and CC is shown in Figure 1.

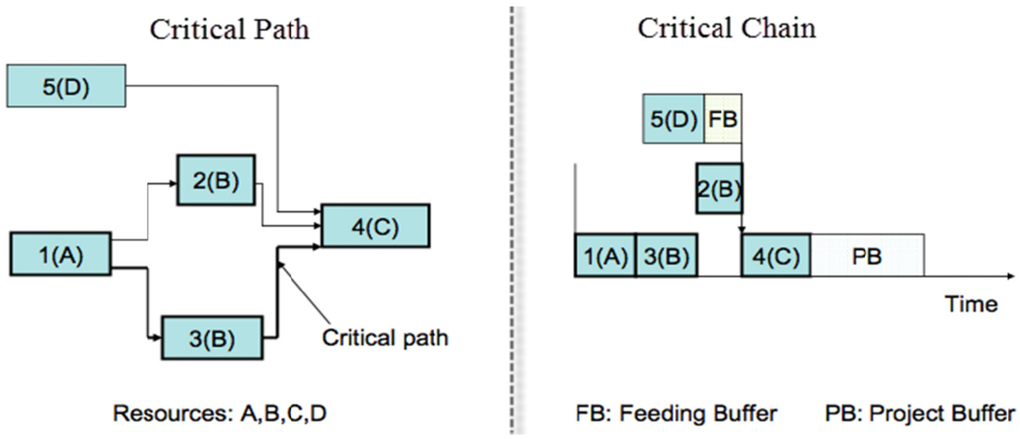

Figure 1: Critical Path vs. Critical Chain (Stratton 2009, p. 160)

CC is based on daily reporting of the expected finish date on ongoing tasks, and is as such a proactive method. Resources are prioritized between several projects or task with the use of a buffer consumption to completion ratio[1], thus enabling a resource allocation system between several projects, which are not to be found in LPS

[1] Consumption of project buffer is measured in relation to the current completion of the critical chain. Projects suffering from extensive use of the project buffer in relation to actual progress are prioritized.

(Koskela et al. 2010). However, CC and LPS differs in many ways, and the adoption of CC as a cost and top management tool might prove difficult. CC, unlike LPS, does not try to reduce the variability in project execution: rather manage the buffers in a new way, resulting in commitment for completion, and visibility when activities get off-track (Koskela et al. 2010). As discussed, it seems that linear models are inappropriate for the design process, which is supported by Ballard (2000a). Thus, there is a need for an inclusive, iterative model in regards to design activities, based on LPS, Scrum and CC.

THE ENGINEERING CASE

The case enterprise is located in Norway, but is part of a global company. The case enterprise has grown quickly, and solving issues with tacit knowledge and personal experience, as was done earlier, is challenging. The research has been conducted within the department for 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 department is self-govern, and delivers products from the product line into the project, in accordance with the project's Scope of Supply (SoS). The product line consists of emergency disconnect packages[1], lower riser packages[2], surface flow trees[3], circulation heads[4], riser systems, control systems, and more.

When new contracts are awarded, a tender phase has been conducted. From the tender, an A4 cost sheet is developed for each individual item in the SoS. A 60-day mobilization phase follows the contract. During the mobilization phase the initial planning is conducted, which sets the milestones for Customer delivery of each SoS. In addition, two stages of design reviews are conducted, defining input for engineering regarding functionality and interfaces to other sub-systems, and external systems. Next, the execution phase is initiated. The plan is static after a baseline, and the progress is reported to Customer in accordance with the master plan. At this stage, the concept engineering commence for each product, and two design review processes are conducted in order to define a final design concerning interfaces, maintenance, manufacturing, installation, retrieval, and cost of the design. The design review processes are conducted in order to freeze requirements, and thus reduce the occurrence of negative iterations due to changing requirements. Engineering for procurement is then finalized, and the procurement process commences. For each SoS the Purchase Order (PO) date marks a significant milestone for engineering.

The planning and progress control of engineering activities are divided into several levels, thus the case enterprise utilizes a planning hierarchy, as shown in Figure 2.

[1] Enables planned or quick emergency disconnect from the Lower Riser Package.
[2] The main safety barrier towards well, which enables well control by cutting and sealing functions.
[3] Topside module for pressure control during flow testing.
[4] A connection to kill reservoir when flow testing is not planned.

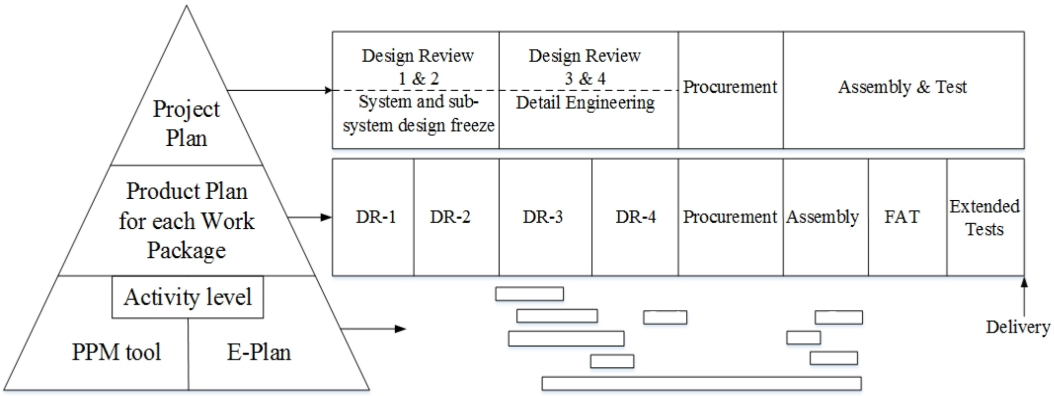

Figure 2: Planning hierarchy used at the case enterprise

The project plan, or master plan, is at the top level in the planning hierarchy. The project plan is relatively low in detail: main milestone dates are shown for each SoS and the plan displays the overall progress of the project, which is reported to the client. At the product level, the plan is more detailed because it includes parts in the assembly. The product plan is a dynamic management tool for each work package and may be rescheduled in order to meet project milestones. At the activity level, activities and due dates are defined. These are the actual engineering activities to be performed, which all ends up in a pure deliverable such as a drawing, document or 3D model. Two tools are used within WAS at the activity level, but 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". The PPM tool is based on frequent progress reporting for each task, as in CC, and Eplan is based on a few milestone dates within each task. The PPM tool was implemented because Eplan do not include all engineering activities. Consequently, Eplan do not capture the actual usage of hours or remaining hours, thus failing to visualize actual status of the project.

Through our initial exploratory study, we have found that neither Eplan nor PPM tool are planning tools; they are merely progress reporting tools. However, the initial planning of the engineering activities, are implemented into both tools to track progress. Activities are often planned in parallel with long durations, without dependency links. In addition, the planning 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. Consequently, on-time delivery (OTD) of documentation and drawings is low for the case enterprise. In March 2014, the OTD was 38 % on average for the ongoing projects. However, the enterprise's OTD is actually better than reported, but because of the poor sequencing of milestones and activities, which determine the delivery dates to client, they seem worse than they are. The enterprise invoices the client according to milestones and OTD; thus, a low OTD will potentially reduce the overall profit of the projects, as well as their reputation.

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

After the quick growth of the case enterprise, planning as was done before seems unsatisfactory. Thus, the problem at the enterprise is likely the lack of collaborative planning and inclusive methods for production control, rather than the tools used for control. To summarize the engineering case, the following points are of importance:

- Insufficient emphasis on the initial planning of engineering activities produces an infeasible, inconsistent plan.
- Production control fails to capture the actual status on the project.
- On-time delivery may increase by the use of inclusive, collaborative methods for planning and production control, i.e. predictability may increase.

DESIGN AND VERIFICATION OF A FRAMEWORK FOR ENGINEERING CONTROL

In this section, we present a construct on how the initial planning and subsequent production control can be strengthen by adapting ideas from LPS, Scrum and CC. Today, the project plan serves as a holistic milestone sheet, which provides input to the different product plans regarding delivery dates of the Scope of Supply. Thus, the synchronization between the different WPs are handled through the project plan, e.g. securing that products from different WPs finish simultaneously for system testing. The product plan is divided further into different milestones for each product and sub-assemblies. These milestones are planned using reverse scheduling where lead-time on the activity, e.g. fabrication, serves as input. Thus, in order to meet the final milestone of delivering the hardware, each sub-milestone in the product plan must be met. 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.

Different engineering activities are performed prior to these sub-milestones, e.g. engineering for procurement, documents for testing, etc. These are currently planned poorly at the project startup resulting in the previously mentioned problems and low OTD. Thus, the initial planning and subsequent production control must be strengthen by implementing all the engineering activities into the product plan. As mentioned, the client requires information regarding delivery dates on all engineering deliverables, i.e. documents, during the mobilization phase. Thus, the product plan must be detailed as much as possible in advance, in order to provide feasible delivery dates to the client. All deliverables are given document numbers, and budgeted amount of hours during the tender phase, which serves as important input when executing the initial planning. The goal of the initial planning is to sequence these 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, to unveil constraints and evaluate the budgeted amount of hours as a collaborative process where different disciplines attend. Thus, the initial planning will be more similar to the phase planning than master schedule planning in LPS. 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 now renders the PPM tool unnecessary. 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 3.

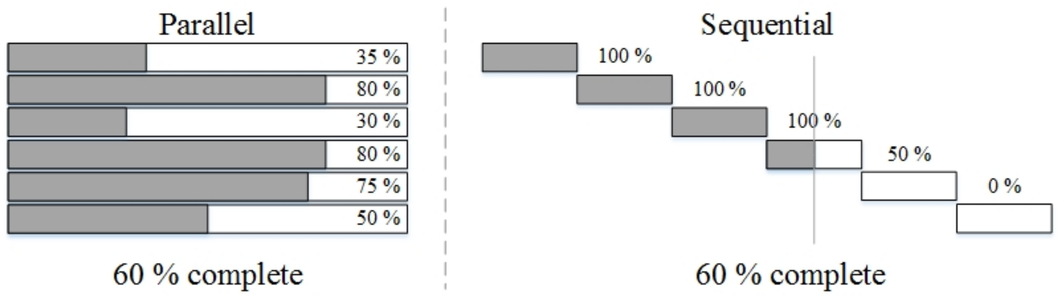

Figure 3: Parallel vs. sequential progress measurement

By structuring activities according to CC, the problems related to multitasking, Student Syndrome, and Parkinson's Law will be structurally mitigated (Koskela et al. 2010). Herroelen and Leus (2001)_ENREF_8 point out that multitasking is quite common in multi-project environments where resources often have more than one significant task running. However, such multitasking result 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 to the end of these chains, as illustrated in Figure 4. The size of these buffers (feeding buffers) must be evaluated collaboratively at the initial planning. No existing method seems satisfactory (Tukel et al. 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 4 illustrates how the logical sequencing of tasks visualizes the upcoming activities for the one 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.

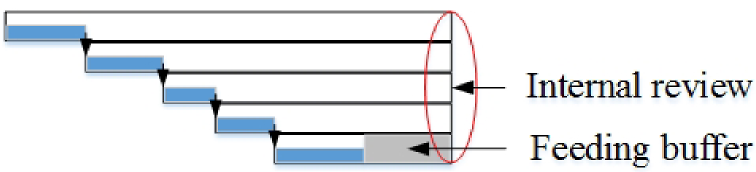

Figure 4: Sequencing of activities with postponed buffer.

For progress measurement, each participating engineer report progress in accordance with the milestones in Eplan. Further, Eplan updates the various 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 et al. 1998; Kalsaas 2013).

However, as LPS demonstrates, planning and production control[1] is 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 should be 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 lookahead 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 et al. 2008). The most challenging prerequisite for the case enterprise 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 (VO), etc. 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. The Lead Engineer is responsible for progress of the WP, thus lookahead meetings are required weekly in order to get frequent update 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). 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.

As initially described, 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, i.e. reciprocal dependencies. Thus, the presented framework might seem optimistic in order to cope with the nature of design activities. A workshop conducted during our study at the case enterprise, where the planning framework presented was developed as a collaborative process for two products in an ongoing project. The outcome of the workshop showed that all documents and drawings could be postponed to the end of the design phase (3D modelling), where the deliverables could be sequenced as described. This is illustrated in Figure 5 for two different products; EDP and LRP. Prior to the workshop, the design and documentation where often conducted as one activity, thus leading to several parallel

[1] 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).

activities with long durations due to reciprocal dependencies between them. With several designers and engineers working in parallel, this often resulted in additional rework, i.e. negative iterations, due to late changes and poor communication. Thus, it was of great importance to freeze the design at some point, in order to make the documentation period sound.

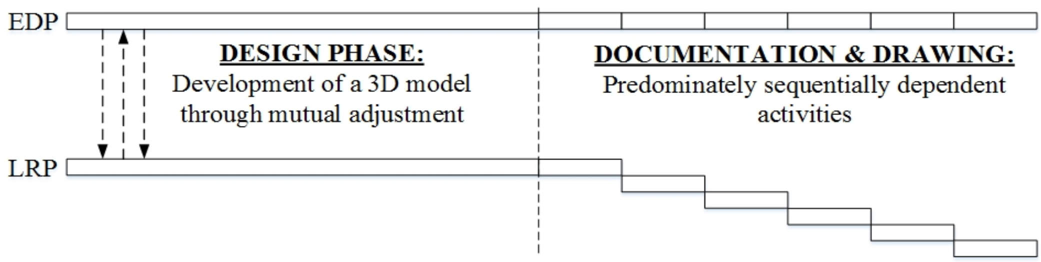

Figure 5: The design phase and the documentation and drawing phase.

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 the frozen increment 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. We believe this is more sufficient 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 to ensure fulfillment of the total scope within the planned period, synchronize with other product designs and provide transparency in terms of progress and cost to project management and 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[1], 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 system engineering must be present in order to set the Sprint Goals and ensure soundness of the design phase. In Figure 6 the Sprints are illustrated as sub-milestones within the 3D modelling. Each Sprint's duration should be less than one month. These must further be implemented in the product plan for cost and progress measures, as described earlier.

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

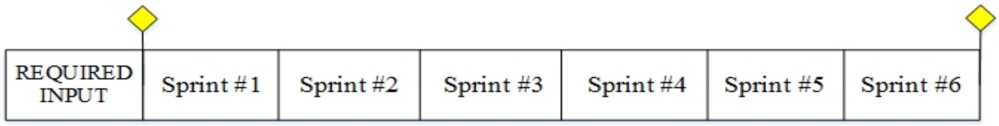

Figure 6: Sprints in the design phase for one product.

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 responsible for the product design, unlike today where several participants may interfere with the current design. The work within the Sprint is carried out in a typical team workflow, as found in sports, where the team collaborates jointly to execute the process and solve problems without lapse in the workflow, as opposed to reciprocal dependent tasks (Van de Ven et al. 1976). 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 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 lookahead meetings are arranged. It is important to arrange these meetings weekly, and not only at the start of the Sprint, in order to make 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 VO occurs it proves difficult to determine the impact on ongoing 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 VO affects previously made decisions, and other products and WPs, 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.

CONCLUSION

The constructive research revealed issues with the case enterprise's planning and production control methods. The main issue is insufficient or incorrect planning of engineering activities resulting in inconsistent milestones, resource allocation and poor on-time delivery of documentation. Based on the nature of design, we address the need for an inclusive and iterative tool with roots in LPS, Critical Chain and Scrum to improve the predictability in complex projects. A new construct for planning and production control of all engineering activities at the case enterprise is presented. The most interesting aspect of the construct is the verification of how Scrum contributes to the division of design engineering activities into Sprints. Self-organizing teams handle these, while the overall production control draws on ideas from LPS. Further, the lacking of a holistic management tool in LPS is handled by ideas from CC, as a postponement strategy is being used.

Future research should monitor the effects of the framework when it is completely implemented at the case enterprise. A deeper evaluation of reasons for non-completion and typical hindrances in the workflow could be of interest, i.e. an evaluation of how the framework could be further strengthen in order to increase the predictability of engineering tasks.

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