TO ACHIEVE PREDICTABILITY IN ENGINEERING

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ABSTRACT

The research question of this paper addresses how to achieve increased predictability in engineering. The research approach is constructive research. It is drawn on theoretical principles and ideas from Last Planner System and from production control in software engineering. Experience indicates that LPS is not adequate to achieve the desired predictability in engineering, but the underlying principles of involvement, continuous learning etc. are applied. The paper provides a solution based on a case study. The business of the case company is engineering, manufacturing and construction of mechanical installations for offshore oil and gas extraction and operations. The constructed solution is based on:

- Delivery of drawings is part of the plan for manufacturing and construction.
- How the delivery of drawings is met by the engineering department is controlled and planned in a separate process.
- Dividing engineering work into phases.
- Division of larger engineering objects into sub objects, meaning control areas.
- The engineering control process focuses on control areas in the various phases.
- A backlog of activities is created, from which tasks are prioritised into so-called sprints lasting for 1-4 weeks. A sprint may be the completion of a control area with a specific maturity in a phase.
- The predictability in the sprint cycles is measured using PPC and causes of deviation.

KEYWORDS

Engineering, control, predictability, LPS, Scrum

INTRODUCTION

Last Planner System (LPS) is a system for predictable production control, where design and engineering is seen as an integrated part of the production (Ballard 2000). Ballard argues that LPS is suitable to control design processes but he was prevented

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from verifying it during his doctoral work from 2000 due to delay in the case project. Hamzeh et al. (2009) reports from an attempt to apply LPS principles in design but the developed model were not verified. Mossman (2013) claims that LPS can be used in the design phase but necessary adjustments are needed.

Wesz et al. (2013) test different solutions of implementation of LPS in planning and control of design and propose a model which differentiates between planning at the department level, concept design team and detailed design team. An attempt by Kalsaas (2013) indicates that even if LPS works well in the physical construction phase certain other steps must be taken for the design process. The underlying principles of involvement, learning and so forth are still relevant, but we need other methods to handle such creative knowledge processes where we find strong reciprocal interdependencies (Thompson 1967) between architect and the different specialities of engineering disciplines. This is especially the case in an early phase of development of design and engineering work.

The research question in the paper is **how to increase predictability in engineering.** In order to illuminate and verify a possible solution work is currently ongoing with a case company which is mainly based on EPC-contracts [1] in engineering, and builds mechanical constructions for offshore oil and gas installations, for example drilling ships and platforms. The case is thus representative in relation to the problem statement (Yin 1994). However, outsourcing different engineering disciplines, the challenges is different when it comes to manage relationships compare to the AEC Industry[2], but the phenomena of engineering is claimed to be very much the same, characterised by strong reciprocal interdependencies, learning and different level of maturity, etc.

The "Constructive Research"-approach (Kasanen et al. 1993) forms the basis of the study. What is constructed is an attempt to improve the case company's system to make the engineering work more predictable in order for the company to achieve increased control of the engineering and production process, from engineering to hand-over of the completed product. Data is gathered by personal interviews, a brainstorm meeting and a survey. The authors have had a more or less daily connection with the case company during the study. Theoretically the paper draws on the principals at the foundation of LPS and other approaches to design and development. Among others, it draws on ideas and concepts from software development.

In the continuation we first and foremost consider the distinctiveness of design and engineering as a phenomenon. Following that the paper considers LPS generally and in relation to design especially. Furthermore the central attributes of the case company are presented, including the method applied in order to achieve improved production control and predictable work flow. As a preparation to construct improvements some conceptual aspects are presented, about waste in engineering, including empirical facts from the case company. In the end a possible solution to a system to achieve improved predictability for engineering in the context of the case company is drawn up.

[1] Engineering, procurement and construction
[2] Architecture, engineering and construction

THE DISTINCTIVENESS OF ENGINEERING

Design as a character and phenomenon is characterized by a balance between creativity and rationality, and is separated from physical production in many ways. Reinertsen (1997) sees design as a process involving both the acquisition of, and production of new, information. Production constructs products on the background of this information. Ballard (2000) has the same views on production, but claims that design produces specifications to the product to be constructed. The design phase is characterized by uncertainty, which is a big challenge to predictability in and between activities (Koskela 2000). The variation in the design process is big, leading to the continuous change throughout the process (Reinertsen 1997).

The design process is normally not entirely a repeatable task, as the solution varies from time to time (Reinertsen 1997). For that reason it is hard to standardize solutions, which leads to a high degree of iterations1. If one is to for example design a structure to hold a certain weight, and the foot print is supposed to stay within a certain area, the first suggestion might not always be the best. Kalsaas (2013) learned that the more time the engineers get to work on a construction, the lower the weight of the result, and further, a reduction in use of materials. Design is a learning process where one develops and optimises a solution. Reinertsen (1997) claims that the cost of making changes in the design phase increase exponentially with the progress. For that reason it is important to consider cost/use in order to find the level of cost the customer is willing to pay.

The design process consists of repeating operations, where one seeks options to re-shape ideas into realities. The process should optimally be carried through in the shortest amount of time which provides adequate reliability at the lowest possible cost (Penny 1970). The starting point for engineering is often a product with a given desired functionality. How one is to reach the result is therefore in many cases unknown. Male et al. (2007) claim that a challenge in design is that problems are illuminated to a larger degree the farther into the design phase one is. This is due to the fact that design needs times to mature.

Iterations are a natural part of the design phase, but not always desired. Ballard (2000) makes a distinction between positive and negative iterations, where positive iterations are the processes which create value. Negative iterations are connected to what is waste in the design process, and what iterations are removable without removing the value creation. Separating these is not easy.

Winch (2002) describes the challenges in construction as "wicked problems". Conklin & Weil (1997) sets forth the following criterion which decides whether a problem is "wicked".

- The problem has locked challenges and demands. The problem is not properly understood until a solution is in place.
- More interests are present, which have a bearing on how the problem is solved. This makes the process to a large degree social. It is also not necessary to find

[1] Iterations are understood as repeating loops of a maturity process in the design development in order to reach milestones as well as making sure activities achieve the correct quality.

the correct solutions, but getting acceptance for the solution from the interested parties.

- The frame works of the solution changes over time, for example resources. This is because we live in a world characterized by change. The operational changes often come from a change of opinion, lacking communication or in any other form which affects how the solution will be.

PLANNING AND CONTROL IN ENGINEERING

LPS[1] was implemented by Ballard and Howard early in the 1990s in order to increase predictability and reliability in construction (Ballard 2000). The focus was first on improving productivity, then on improving predictability in the work flow. The change in concept was inspired by the production system/lean production of Toyota and Koskela's (2000) work on the production theory known as TFV-theory, where T=transformation; F=flow og V=value. It is especially the flow-part which is tied to lean construction, while transformation is associated with the measurement of productivity.

One main problem in design is that changes occur often, and the insecurity concerning information is big, especially in an early phase. Mossman (2009) considers meetings with "bad information" as positive. Mossman's point is that it provides an opportunity to tackle the problems early and enter a mode of problem solving. Kalsaas (2013) refers to attempts where the ordinary layout and content of the LPS-phases did not work. The attempt was made in the design phase for a company which builds mechanical constructions for offshore oil and gas installations. In the same work Kalsaas argues that a supplementing method is needed in order to cope with the actual engineering process based on its distinctiveness. He points to the needs to work more after short sighted milestones tied to deliveries to fabrication and assembly. Based on this recognition an idea was identified to assess the Scrum method (Schwaber & Sutherland 2011) applied in software engineering as a source of inspiration to handle and control the short sighted processes of engineering.

Scrum is inspired by a term in the sport rugby, “not an acronym, but mechanisms in the game of rugby for getting an out-of-play ball back into play” (Schwaber & Sutherland 2011, 33). The reasoning may be linked to lean philosophy where one tries to make complex systems simpler, short sighted and to capture critical activities. The sprints or time frames are periods continually controlled through division of the work in relatively small packages. The scrum team produces the product in accordance with prioritised work tasks based on dependencies and value for the customer at the actual time. The work proceeds in loops where daily meetings are used to maintain the control of progress and critical activities (Schwaber & Sutherland 2011).

[1] LPS: Last Planner System is a trademark of the Lean Construction Institute

COMPANY CASE WITH ENGINEERING, MECHANICAL FABRICATION AND CONSTRUCTION - CHALLENGES

The case company is a mid-size company with 350 permanent staff (at times closer to 600 contracted in projects). The engineering department 43 employees (including temporary personnel) which is the case for the paper cover 8-10 engineering disciplines including layout, mechanical, main steel, outfitting steel, piping and pipe support, electrical, fire prevention and safety. Most engineering tasks are for the most part performed by own employees, but the company also outsources depending on the need to increase capacity and cover non in-house disciplines, including electrical work.

Qualitative interviews with engineers in the case company reveal that as of today there is no well-functioning system for the completion of a project. According to one respondent a new project is started with a clean sheet of paper. There is little standardization and lacking procedures, as well as varying attitudes to maintain deadlines. Several respondents experience that the communication and flow of information both internally and externally is inadequate. It is not unusual that a failure in communication leads to faults where the case company often has to cover the costs of repair. What emerged was that constant change in design and solutions is a big problem in the engineering department. These changes occur both internally and from sub-contractors, and the problem increases with the time frame of the design process. Variation work may occur within most disciplines, but the discipline which is always affected by change is pipe support[1]. If they have completed a task, but some of the previous activities need to be changed, they need to re-design their work independent of the size of the change. A project may cause the loss of more than 1 000 man hours due to changes such as these.

Iterations may also be positive, but this only applies when its part of the development phase is already communicated. The problem of today is that there is no clear system which may clearly state whether we are in the layout phase (concept development) or the phase where the disciplines have agreed upon interface and limited areas. There is also no clear system for "freezing"[2] activities. The engineers generally only have a superior plan for the day, and they have never had a plan for projects at a detailed level, according to gathered information. This means that there is no common priority of activities which should be performed except some ad-hoc meetings.

Conducting engineering work is connected to risk. Gathering adequate information/output for tasks to be done is at times very demanding and time consuming. If the information is not gathered by the time the task is to be performed one faces a cross-road. One way is to complete the task by putting limitations based on experiences and how one thinks it will turn out. In this case one accepts the risk even if the actual conditions do not match the assumptions. The other way is to present the assumptions to the client and ask for accept. By accept the customer accepts the risk if something should go wrong. Establishing the risk-taker is time-consuming and not always easy. Customer hesitation of accepting risk is a normal phenomenon.

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[1] Pipe support makes for example suspensions for pipes and electrical components

[2] By "freezing" is meant that an activity is finished of preliminary finished so that other disciplines may perform their tasks while not being unsure whether the area or system is clear.

The case company has in its quest for control of its engineering work started to divide the engineering work into four phases; layout, design, detailing and drawing, as exemplified in Figure 1. The biggest part of the creation of value happens in the first two phases and the creation of value towards the drawing phase is decreasing. The first phase may also be characterised as a development phase with a high degree of reciprocal dependencies where "everything affects everything". This is also why the first phase is characterised as multi-disciplinary. The reciprocal dependencies are reduced towards the drawing phase, and the sequential dependencies are more forthcoming. On part of the foundation of the idea is that one should not go deeper downstream in the value chain than necessary at any given time to discover changes, leading to the reduction of extra work due to changes.

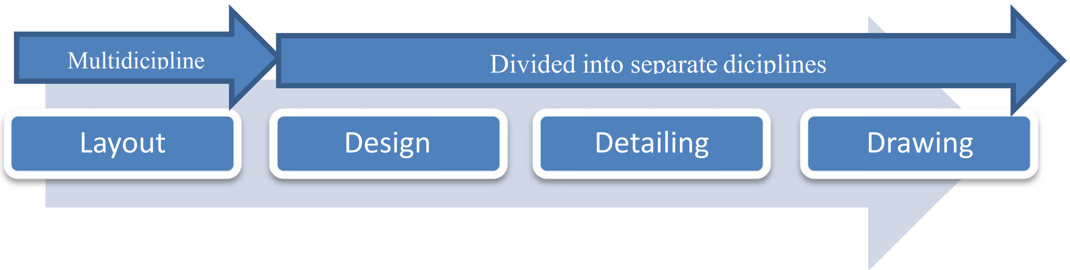


Figure 1: Phase division in the one project of the case company.

The phase division makes it further easier to outsource one or more phases, and especially those farthest to the right where the creation of value is least and where there is least uncertainty. The work of producing drawings based on a 3D-model may be characterised as a resource-decided activity as the work of performing the work is about proportional to the number of resources (Attrup & Olsson 2008), so that four people work twice as much as two. This feature leads to companies having the opportunity to outsource the work to a low-cost country with sufficient capacity, and achieve cost-savings and postponement in the engineering work. This is contrary to the Layout phase where there is a high degree of uncertainty and increasing staffing may have little effect. These activities are labelled problem-decided activities (op cit.).

COLLABORATE PLANNING EXECUTION (IPE)

The work of improving control and predictability in engineering is a part of a lager project labelled CPE, which is the translation by the case company and an adaptation of LPS for its own needs. The underlying principles of LPS are the foundation of the control and planning system for engineering. The identified principles of LPS at the foundation are (Kalsaas 2014):

1. Increasing degree of de-centralised control towards execution (non-deductive perspective)
2. Collaboration across trades and disciplines
3. Involvement of all employees, even the single worker ("The Last Planner")
4. Focus on continuous improvement and learning

5. Put pull principle at the foundation for production and engineering control.
6. Simple and manual planning techniques

The case company is working as a part of CPE to introduce an original commissioning system for the entire value chain of the company. The system labelled PIMS (Project Information Management System) is based on a Stage-Gate logic, in which the phases of engineering, explained above, are important mile stones and stage-gates. Each stage-gate includes a check-list based on demands to delivery from the different phases. In an early development phase it is registered that PIMS is especially advantageous in increasing input control and control of necessary prerequisites from the customer. Difficulties in separating the various phases due to the nature of the engineering with a gradual maturity, learning, changes and loops are furthermore observed.

Kalsaas (2014) illustrates an intended phase plan for a 24-month long project where fabrication and engineering are integrated with a specialist plan for procurement. In order to make the plan transparent it only includes important and principal milestones for fabrication and engineering. The various disciplines work with its own dynamics, and for that reason it is more appropriate to treat them on their own with own work plans. By locating the common points for the disciplines in the project one obtains an overview over what should be finished when, and what activities are less critical in for example the start-up of the project. This may typically be to postpone a drawing as late as responsible.

WASTE IN ENGINEERING

Design and engineering may be seen as an activity which creates value for both client and users by creating functionality, but also through aesthetics. Set against this we may understand fabrication and construction as a realisation of the values from design and engineering. In design it is thus important to create solutions which are beneficial to fabricate and construct, and at the same time are beneficial to users and the management of what is built (Kalsaas 2013). In this section the focus is on waste in engineering as such.

Marzouk et. al. (2012) points to three drivers for waste in design, which are uncertainty, waiting and heavy flow of transmission. Engineering consists of both a production process where information is produced and a creative process where potential value is created. Both processes have their drivers for waste. The design phase is in addition characterized by strong dependencies between disciplines where there is little doubt that insufficient coordination may be a source of waste, which is difficult to identify (Koskela et. al 2013). This is underscored by Kalsaas (2013) when he claims that the design process is strongly influenced by reciprocal dependencies, especially early in the development phase. This make coordination in design demanding, and based on Thompson (1967) a mutual adjustment as a coordination methods is a prerequisite, while plan is a suitable coordination method for sequential activities. See for example Kalsaas & Sacks (2011) who analyses LPS in relation to Thompson's conceptual framework in connection with dependencies and coordination.

We arranged a brainstorm with employees from the engineering department (12 engineers) to define sources of waste in the engineering processes. This is further elaborated on in the next chapter. The main identified sources of waste:

- Engineering without adequate input, for example, loads of equipment, etc.
- Demanding to gather information from external actors, e.g. the client and his subcontractors
- Engineering is detailed too early, which lead to the disciplines comes out of balance (different level of maturity)
- Poor flow of information
- Changes from external actors which are not billable
- Extra work and unnecessary risk caused by client reluctance to make decisions (risk aversion by the client)
- Lack of software licenses and/or inefficient software
- Lacking procedures, standards and organisation for the completion of the project

REGISTERED WASTE OF TIME IN DESIGN IN THE CASE COMPANY

When constructing a control system for engineering it is important to achieve an understanding of what are the sources of waste, which we seek to avoid. We gathered waste data from engineers (12 persons) over a period of two weeks. The waste is characterized as time thefts. Data was gathered daily by self-reporting by the individual engineers. A questionnaire with pre-determined categories of sources of waste was prepared. The finding from the earlier reported brainstorm meeting and individual interviews was the basis for this limited survey. The findings are presented in Figure 2 and 3.

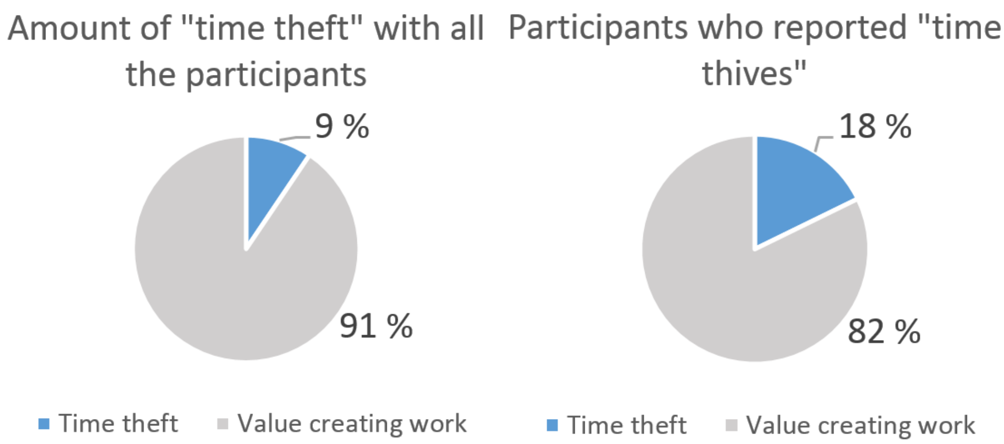


Figure 2: The diagram to the left indicates the amount of time all participants in the survey reported as time-theft.

Figure 2 indicates all reported time-thefts from the survey. The total number for that week indicates that 9% of the working day is waste. This corresponds to 132 hours of a total of 1398 hours. The validity of this result may be somewhat weak as 47% of the total number of surveys submitted did not report any time-thefts in the period measured. This is thought to be due to a lack of motivation to participate in the survey. By excluding these surveys the graph to the right in Figure 2 indicates that waste measured in time constituted 18% of the working day, or almost one day of the five day working week.

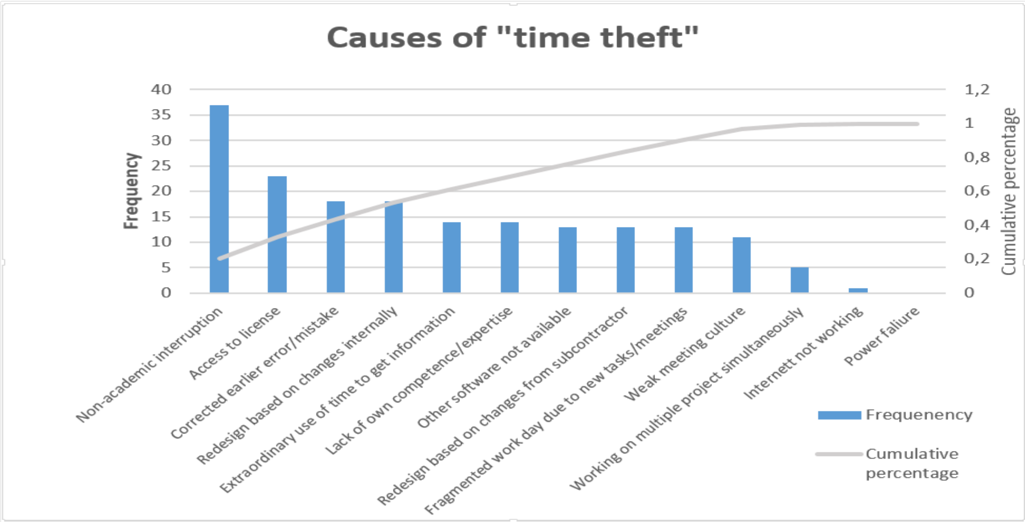


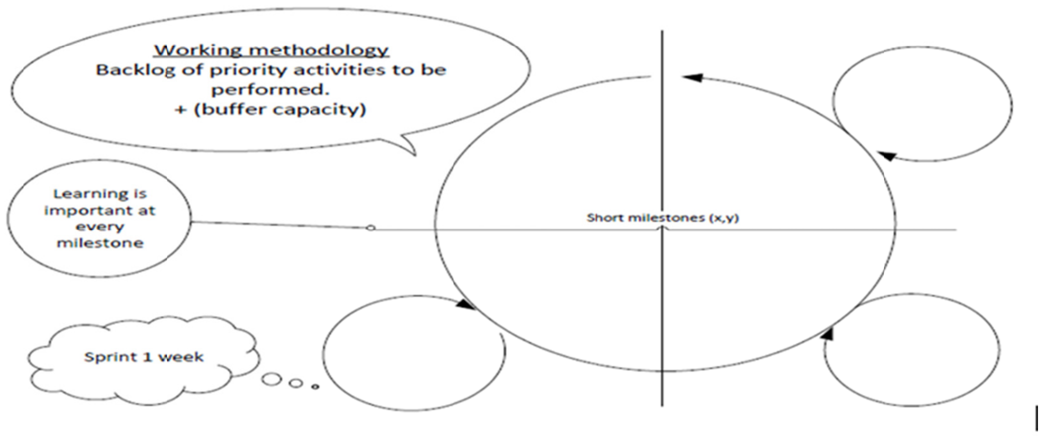
Figure 3: Distribution of time losses by cause.

Figure 3 illustrates that non work-related disruptions is the most frequent time waste. Furthermore do we see that the various categories are evenly distributed, except electrical power failure, down time due to internet and working on several projects at the same time (multitasking), which is significantly lower than the other waste sources.

CONSTRUCTED OUTLINE OF PLANNING AND CONTROL IN ENGINEERING

In Figure 4 we illustrate a possible solution to medium and short term planning of engineering in the studied case.

Start date	End date	Description	Control area	Resp. Person	Module	Phase	Milestone	Characteristics of completed task	Status
10.02.2014	10.04.2014	Interface register/Drawing for Escape routes 07.04.2014 Will be issued this week	All	ErT	Top side	Drawing	TS13 completed	Drawing issued	Closed



Start date	End date	Description	Resp. Person	Task completed	Completed on time	Reason for not completing task
17.03.2014	11.04.2014	We need to check the HP mud platform below Mud/Cement MF. Should it go away? 07.04.2014 JaW will send an Email regarding this. This week after some clearifications	JaW/MoH	Ongoing	No	Email sent. Waiting for clarification form NOVK

Figure 4: Illustration of a construct for planning and control in engineering

The idea behind the construct for which we have just started to test is based on the Scrum method where design engineering replace software engineering.

Software engineering in modern object orientation languages is developed in procedures with often quite clear cut input and output interfaces to other procedures. A sprint can then be to create a larger procedure or a set of procedures. These procedures we can see as control areas in construction and engineering, also denoted zones. When we want to create control areas in for instance drilling modules we can divide above and below drill floor, left and right. We don't have the clear interfaces with such control areas as in software engineering, but it is much better compared to not operate with control areas, according to experience in the engineering department.

In addition to operate with control areas we need to differentiate between phases in engineering, at least between concept design and detailed design as in Wesz et al. (2013) or based on the four phases in the case company (Figure 1). The sprints are most likely to be most important in the layout phase, and maybe also in the design phase as there are common to go back and forth between the early phases, which is also confirmed in praxis. When entering detailing and especially the drawing phase we can more rely on sequential planning and control techniques as the phase are predominately based on sequential interdependencies. Delivery of drawings to fabrication and construction need to meet these activities milestones for production. Sprints in engineering are set accordingly.

A sprint will typically be organized around a zone or a system as control area. A system can be a piping system. In addition we need to consider the maturity level for each control area and phases. To complete a sprint can take 2-4 weeks. Sprints are moreover coordinated on day to day basis in short morning meetings for mutual adjustments between the engineer disciplines. It is certainly an advantage in the studied case that most of the different disciplines are located in the same office. Sprints area a list of activities for what to do, which are selected from a larger list, a back log. The work through sprints goes in loops where the main focus is control and progress of critical activities.

CONCLUSION

The paper draws up a possible solution for increased predictability and production control in engineering. Key characteristics of the solution are:

- Delivery of drawings is part of the plan for manufacturing and construction.
- How the delivery of drawings is met by the engineering department is controlled and planned in a separate process.
- Dividing engineering work into phases.
- Division of larger engineering objects into sub objects, meaning control areas.
- The engineering control process focuses on control areas in the various phases.
- A backlog of activities is created, from which tasks are prioritised into so-called sprints lasting for 1-4 weeks. A sprint may be the completion of a control area with a specific maturity in a phase.
- The predictability in the sprint cycles is measured using PPC and causes of deviation.

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