

To Achieve Predictability in Engineering Management

Bo Terje Kalsaas¹

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 (LPS) 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 from engineering is part of the plan for prefabrication and construction, but controlled in a separate process.
- Engineering is divided into phases.
- Engineering objects are split into sub objects or control areas.
- The control of engineering is based on a combination of control areas and phases.
- A backlog of activities is created, from which tasks are prioritized into 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, offshore construction, mechanical industry, LPS, SCRUM.

Introduction

Offshore projects tend to be large-scale, the financial impact of delays is significant, and the environmental and human consequences of engineering failure are likely to be very serious. Severe accidents offshore have provided the impetus for several improvements of technical safety regulations (Kalsaas 2013). Engineering for these conditions may be bordering on the extremes of previous experiences with drilling depths, climate and wave conditions, and fire risk. Due to the context, a strict QA and QC2 regime applies to offshore construction projects.

On the production side, the industry seems to use planning strategies inspired by “stage gate” (Cooper 1988) and “waterfall” (Conklin and Weil 1998) models. Christensen and Kreiner (1991) have characterized this linear approach to planning as rationalistic. In their most exaggerated form, such models are based on the machine metaphor with a focus on optimization within the triple constraints of time, cost and quality (Tryggestad 2012). Experiences with rationalistic approaches have shown that they fail to capture the dynamics found in Design Engineering, where knowledge and problem solving develop gradually in learning processes based on experience (Kolb 1984; Kalsaas 2012). Conklin and Weil (1998) illustrate this in what they call “the earthquake”, where problem comprehension and problem

¹ Professor, Dr Ing, School of Business and Law, Department of working life and innovation, University of Agder, 4846 Grimstad, Norway, Mobile +47 97082582, e-mail: bo.t.kalsaas@uia.no

² The NORSOK STANDARD S-001 on technical safety applies to the oil industry on the Norwegian continental shelf. The classification society DNV has its own standard (DNV-OS-A101); this is similar to the NORSOK standard, and applies globally.

solving takes place during all four phases of a waterfall model: 1) gathering data, 2) analyzing, 3) formulating and 4) implementing solution.

This is the background against which more iterative and collaborative methods for planning design and engineering must be sought in order to improve the predictability and quality of drawing deliveries. And this is where inspiration from “Scrum” (Schwaber and Sutherland 2011) and “Last Planner System” (Ballard, 2000) comes in as alternatives to the more system rationalistic approaches to organize and manage engineering processes. Scrum is also characterized by some authors as “Agile planning” (e.g. Wysocki 2009). Lean Project Consulting have launched what they describe as “Responsibility-based Project Delivery”³, a concept aimed at Design of onshore construction projects that builds on Scrum and agile adaptation (Macomber and Bettler, undated) combined with ideas from Lean. The Scrum methodology is taken from the IT project discipline, whose knowledge processes are claimed to have many similarities to those found within engineering.

Hence, the research question addresses how to develop an integrated project engineering delivery system based on design engineering theory. The fact that we use design engineering theory as our starting point distinguishes our approach from the generic project management approaches, such as stage gate, waterfall, PMI’s model (PMI 2013), etc. Furthermore, our approach accords with Ballard and Koskela’s (2012) idea that the starting point for theory about management should be sought in production, not in management and organization theory. The authors argue that there is a blank area in management science as a result.

Important requirements of such an integrated delivery system is that it must ensure necessary control of quality, progress and cost while including the iterative and collaborative approach adapted to design and engineering understood as learning and knowledge processes. This means integrating not only iterative concepts, but also linear ones, as the latter are considered necessary for the ability to report on progress, cost and quality. The Last Planner System⁴ does not include such functionality.

Method

The method is based on a constructive research design for analysing 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 artefacts, 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 the authors are working closely with the case enterprise.

The case enterprise is in the process of developing and implementing an engineering (and fabrication) management system of the kind suggested above, titled “Collaborative Planning Execution” (IPE).

The Case Enterprise

The case company for the IPE development work – described henceforth as “the Vendor” – is a supplier of engineering, fabrication and installation of mechanical constructions for the oil and gas industry. Typical products are various types of modules for drilling rigs and ships, for example mud modules, derricks, drilling floor with sub-structures, and other topside modules.

³ © 2011 Lean Project Consulting

⁴ Trade mark of Lean Construction Institute

In the following section of the paper we focus on the phenomenon of engineering design before describing and explaining the operationalized integrated engineering project delivery model. This is followed by a presentation of findings from the studied case related to theory on design engineering in general, and findings that are specifically related to the proposed model for integrated engineering project delivery.

The Nature of Design and Engineering Work

With the traditional linear planning models in mind, Reinertsen (1997) argues that existing descriptions of the nature of design do not reflect the practical world. This is in line with Austin et al. (1999), who argue that traditional planning techniques are not suitable for design work because they are incapable of dealing with iterations in the design process. Koskela et al. (1997) found clear evidence in their review of the literature that chaos and improvisation are substituted for planning and control, leading to flaws. Ballard (2000) introduced the concepts of “negative iteration” and “positive iteration”. The starting point for positive iteration is that in order for alternative solutions to be understood, good designs must be produced for the incomplete or provisional outputs.

Reinertsen (1997) argues that the due-date delivery problem in design is rooted in the general variability of the design process. Arguing that probability distribution functions should be used to describe the duration of activities, Vatn (2008) follows up on this point. According to Reinertsen’s (1997) data, the design effort ceases when the designers run out of time. This can be interpreted as meaning that the ideal solution is unattainable, and that decisions must be made in terms of what solution can be regarded as good enough (Bølviken et al. (2010).

Male et al. (2007) identify three problems that are particular to design, namely: 1) requirements are often vaguely stated and interpretations of problems are subjective; 2) problems become progressively clearer as solutions evolve; and 3) the process is multidimensional, highly interactive, and represents the interests of many stakeholders.

Winch (2002) describe the challenge in construction projects as the “wicked problems”, these are problems that are uncertain in the sense of being ill-defined and without an optimal solution, which can be linked to the involved dependencies between disciplines. Thompson’s (1967) concepts of dependency and coordination can help create a deeper understanding here. Thompson distinguishes between sequential and reciprocal dependency, identifying the coordination technique tied to the former as planning, and to the latter as mutual adjustment. Kalsaas and Sacks (2012) argue that planning often fails to produce the desired result as a result of failure to understand the qualities of the different dependencies involved. When Smith and Eppinger (1997) describe coordination as negotiation between technical specialists, this exemplifies mutual adjustments, which we regard as a fundamental coordination method in design. At the same time, however, more traditional planning techniques must also be used in order to handle the sequential dependencies.

Ballard and Koskela (1998) argue that design processes should include three perspectives: conversion, flow and value generation. In terms of method and practice, the conversion perspective is associated with WBS (work breakdown structure), CPM (critical path method) and organizational responsibility chart; the flow perspective with rapid reduction of uncertainty, team approach, tool integration and partnering; and the value generation perspective with rigorous requirement analysis and systematic management of customer requirements.

The Engineering Case

The Vendor's engineering department deals with the disciplines of layout, main steel, outfitting steel, pipes, pipe support, weight control, electricity, IT, HVAC, and technical safety. Main steel is typically the first discipline involved. It depends on information about the machinery to be installed and used on the completed platform, such as winches, rough necks, pipe handling machines, drillers' cabins with control systems, compressors, pumps, and cranes for drilling operations and handling of materials. Next in line are the major pipes and cable ducts which connect the drilling equipment and the outfitting steel, whereas minor pipes and cables are routed around the main structures. Escape and access routes during the operation phase are an important part of the final layout. Moreover, pipe support constitutes a crucial interface between steel and pipes.

The main case described in this paper is a pure engineering project in which the Vendor engineers modules for a drilling vessel. Decisions are yet to be made as to who will fabricate the designed and engineered products. The Vendor is part of a long supply chain, whose end customer, a Brazilian oil operation company, has contracted out the design work to a specialist naval architecture and marine engineering company. This company has contracted out the equipment design to a drilling equipment supplier with global operations; which has in turn contracted out some of the work to our case company, the Vendor. The Vendor also uses a sub-contractor for some of the engineering work, and along with the Vendor, other companies with fabrication capacity are also engaged in engineering modules for the same project. The engineering work involves close communication between the Vendor, the equipment supplier, and the marine engineering company in the endeavour to find good engineering solutions. The main case has a budget of 76,000 engineering hours (approximately 10 mill US dollars).

The engineering process means that the customer provides the Vendor with a concept and a set of requirement specifications. These include elements such as a rough sketch of the location where the drilling equipment will be used, and functional requirements following from the conditions that will be surrounding its use (ocean depth and geography/climate). Based on the provided information, the Vendor will start to build a 3D model. Fabrication feasibility is an important concern when engineering solutions are chosen by the Vendor. However, this concern must be carefully weighed against user interests tied to the finished product – including HSE solutions – which are determined during the design phase, and encompass the lifespan perspective. These are important aspects of delivering customer value, which is a central concern in Lean Construction.

Operationalization of the Integrated Project Engineering Delivery System

The operationalization is illustrated in Figure 1. The types of plan mentioned in the figure are as follows:

- Level 3 plan: A rough milestone plan that is included in the contract with the customer / the letter of intention
- Level 4 plan: A strategic network plan. Budget figures are linked to the main activities. Used to report back to the customer on progress and financial status, and for internal control of costs and progress.
- Phase Schedule: This is a multi-disciplinary iterative planning process which uses the method of reverse scheduling. The idea of the reverse approach is to generate upstream pull in the value chain, both internally and externally. Milestones and main activities are in focus.

- Lookahead schedule: Its main purpose is to certify that activities are sound before they are implemented. The lookahead schedule is important in that it helps ensure an increasing degree of predictability as the implementation date approaches; and as an arena for registering changes. The schedule is prepared and updated at interdisciplinary meetings, and the focus is on dependencies between different disciplines.
- Action plan: This is a plan for the week during which the work is implemented. Each discipline prepares an action plan – a schedule of activities – for its own employees. The plan is prepared by the head of the discipline in cooperation with his or her team members.
- Quality Control: Engineering has prepared the use of a commissioning system (PIMS) for its detailed follow-up and quality control.

The level 4 plan is a traditional CPM-oriented plan made up of tasks and milestones represented as a Gantt diagram. The Quality Control System, PIMS, is based on using work packages as input, and then applying stage-gate logic to monitor and control these packages throughout all phases of the design process. The phases can also be regarded as a value chain for design objects, and there is quality control of every link in the chain. If aspects are found lacking, the work packages and objects are subjected to amendments, or so-called punch. The iterative and collaborate elements of the operationalized system are the phase plan and the lookahead schedule.

In terms of the three perspectives proposed by Ballard and Koskela (1998), the Level 4 plan and the QC system represent the “conversion” perspective; the phase plan, the lookahead schedule and the action plan represent the “flow” perspective; and the “value generation” perspective is captured in the translation of the customer requirements into engineering method, and in the collaboration with the customer during problem solving. The routines for reporting back to the customer can also be seen as part of this third perspective.

The QC system is not a planning system, and dates for the work packages are derived from the Level 4 plan, which is prepared on the basis of the phase plan. The Lookahead schedule process is used to update the set dates in the QC system in our operationalization. Each engineering discipline reports on its progress in the QC system, and reports from this system are imported into the Level 4 plan, under which periodic reports about progress and costs (time use in relation to budget) are submitted, according to contract, to the customer. Work packages identified in the QC system are declared sound in the Lookahead schedule. Furthermore, buffer activities are identified in the Lookahead schedule, which provides input of sound activities to the Action plan. A comparison between planned and implemented activities is also included, as illustrated in Figure 1.

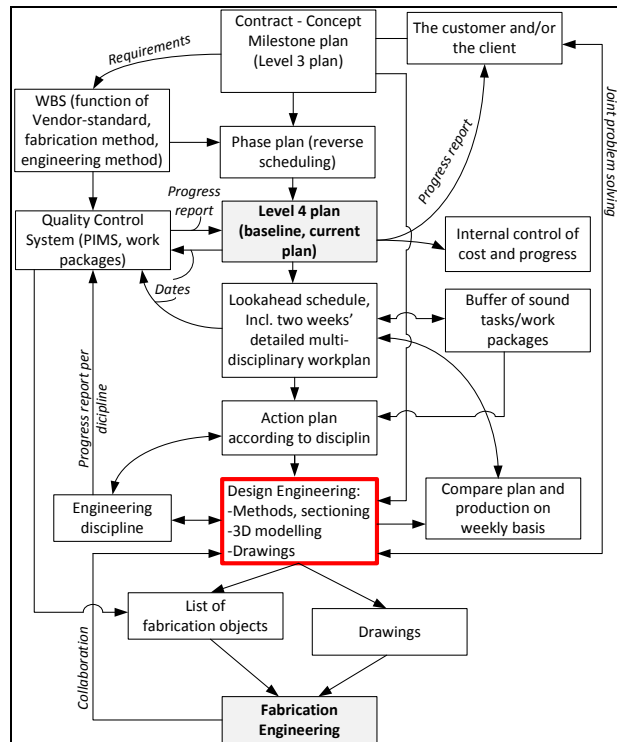


Figure 1. Operationalized integrated project engineering delivery system

Findings

This section is divided into two parts. The first of these deals with findings related to the theories on design presented above; the second discusses preliminary findings related to the process of implementing the integrated project engineering system.

Design Engineering

It has been confirmed beyond doubt that understanding of problem scope as well as ideas for possible solutions develop gradually among the participants across the different phases; it thus makes sense to speak of the knowledge involved in terms of different levels of maturity. This confirms the theories referred to above. The implications of this for the declaring of activities as sound will be addressed below.

Furthermore, we find that there is considerable cooperation aimed at solving engineering challenges two tiers upstream in the Vendor's value chain in this project, which includes the Vendor's customer, the drilling equipment supplier, and the main contractor for the client. The Vendor's engineering manager finds the project very engaging since what the customer wants is clearly expressed, comparing it to another project where the customer had few visions beyond wanting a drilling vessel that would be approved by the relevant classification society. In the case project, the perception of the engineers is that they learn a lot from the joint problem solving process. This collaborative process is also very central for value generation; confer the three perspectives on a design process.

As to the point that the ideal solution is unattainable, an experienced project manager claims that in his experience, engineers manage to reduce the weight of the drilling vessel or platform if allowed enough time. This is important for the end product and for the amount of steel eventually used. However, allowing the process to include this weight-reducing stage is not always possible for budget or progress reasons.

Furthermore, this project confirms that customer requirements are often vaguely stated and that for some elements, no scope is provided until far into the project. In a system where everything is mutually connected, this can generate many technical changes at a later stage. Customer failure to work through the problem solving aspects sufficiently to arrive at a mature understanding seems to be the cause when clear definitions are missing. This may in turn be a result of capacity problems in a market with high demand.

In one case the engineering manager refers to a meeting with a customer and the customer's client that lasted several hours but resulted in few if any decisions, interpreting the problem as a case of Mr X being unwilling to make decisions because he feels that there is too much uncertainty involved. The Vendor's engineering manager relates that "a full overview is only achieved when the engineering project is virtually ready for delivery", arguing that the work must concentrate on minor technical matters, temporary decisions must be made on the basis of these, and iterative work must be done on minor as well as more major aspects, systematically removing uncertainty. In addition, there may be commercial interests tied to late decision making on the customer side, as it might save the cost of having to pay for changes.

It hardly comes as a surprise that reciprocal interdependency is a major aspect of the engineering process. A couple of handfuls of different engineering disciplines are simultaneously working on the same object to gradually ensure that the solutions for its different parts and larger units become more mature, making the mutual adjustments achieved through formal meetings and brief but frequent informal conversations throughout working hours on a daily basis across different disciplines absolutely essential. Especially during the early phases, the engineering work is a matter of trial and error in the search for potential technical solutions to the problems defined by different disciplines, not only one's own. When this is achieved through mutual adjustment, it can be associated with "positive iterations".

Preliminary Experiences in the Effort to Implement the Integrated Project Engineering Delivery System

Many weeks into the work on the main engineering project studied in this paper, a contract had yet to be established. Combined with numerous delays on the part of the customer, the lack of a contract created a degree of planning uncertainty. An agreement ensuring that the Vendor is paid for the work done was, however, in place.

The engineering project consists of four modules. Initially, a phase plan was made for the engineering of a mud module. The plan had a timeframe of 14 months, and was prepared in the traditional way of establishing milestones and placing activities for the different disciplines sequentially on the timeline. In reality, this plan has collapsed, and could barely be used even as a basis for the Level 4 plan. There are many reasons for this. One reason is that no suitable engineering WBS had been established. This must be understood in light of the fact that the engineering department had no previous experience of managing projects in a detailed manner. Furthermore, it would appear that detailed planning of engineering activities beyond a horizon of a few weeks is impractical due to the inherent variability and the need to take into account that problems become progressively clearer as solutions evolve. In the phase plan we identified a large amount of necessary information that must be collected before the engineering work can begin. We also saw, however, that the work commences even without this case-specific information, building on the experience gathered from past projects, especially by the most experienced engineers.

A phase plan for a Top Side (TP) module has later been prepared. As a basis for this work, the engineering department decided to divide their engineering work into four phases: 1) Layout, 2) Design, 3) Detailing, and 4) Drawing.

In the work of making a phase plan for the TP module, we made changes based on the experiences from the failed first phase plan attempt. We now established a rough milestone plan for the entire project period, concentrating on the nearest milestones. Two maturation levels were defined for the Layout phase: ML1 and ML2. The content of these milestones was also defined. In other words, we answered the question “What engineering must be completed at what maturation level for the different disciplines?” This was done jointly three weeks prior to the deadline for ML1. As it turned out, ML1 collapsed for all of the disciplines except main steel, whose clarifications for continuing the work towards ML2 had been secured. The rest of the disciplines were still waiting for vital information from the customer. This also suggests that there may be good reasons for differentiating the milestones along discipline lines. Furthermore, it shows that in this type of mechanical engineering, what matters above all is that the main steel engineering work can continue, as it lays the basis for the other disciplines. Release of sections for pipe support can serve as another important milestone of this type.

Another experience from the phase planning for TP module is that when we asked “what must be done in order to succeed at meeting ML1”, the disciplines produced responses that included a series of actions, such as meeting the customer to produce decisions and requirements regarding structural loads, etc. In our model, such items belong to the action plan, not the Level 4 plan.

Despite several attempts, we have not yet succeeded in activating the Lookahead schedule. One reason is that the QC system has not been sufficiently integrated; another is the continuing uncertainty linked to lacking information and decisions from the customer. The designed concept for declaring activities sound in the engineering lookahead rests on four factors: 1) external information, 2) internal information, 3) preceding activity, and 4) staffing. In terms of factor 1, we are faced with the dilemma that we must expect the information to be limited. Thus it is rather a matter of whether sufficient information has been made available for commencement of the work to make sense, and to proceed from there, possibly in collaboration with the customer, to increase the maturity.

We see that engineering is different from fabrication and physical construction in the sense that in those areas, work should not be started until all of the seven flows are in place, in order to avoid the waste-generating mechanism of “making do” (Koskela 2004). In engineering, “making do” can be regarded as part of the normal work process of design engineering, provided that it is a matter of positive iterations.

Thus far into the project, reporting on costs and progress from Level 4 has not yet commenced. This is due to the fact that we have not yet progressed sufficiently in the endeavour to integrate the QC system with the other elements.

The planning meetings are integrated with weekly technical design review meetings, and during discussions between the disciplines of different technical solutions relating to the 3D model projected onto a wall, actions and needs for decisions are simultaneously and collectively identified and written down on a whiteboard. This seems to function adequately.

Conclusion

Based on experiences from implementing the proposed integrated project engineering delivery system so far, we have identified some necessary modifications to the operationalized system. 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.

Experiences from the project so far confirm previous findings and theoretical points from the literature – for example that understanding of scope and possible solutions emerge and mature over time; that the reciprocal interdependencies are considerable; and that the ideal solution is regarded as unattainable. This latter point can be exemplified by the fact that the longer the solutions are allowed to be iterated by the different disciplines, the greater the final weight reduction. Moreover, we see that requirements are often vaguely stated, creating a great need for interpretation. Technical solutions are found by the technical experts in negotiations and joint learning processes. The rationalistic and linear models for project execution seem incapable of handling design and engineering as witnessed in the case company during this engineering project. Hence, although considerable changes must be made to the operationalized model, the iterative and collaborate methods will be at the basis of its further development.

References

- Austin, S., Baldwin, A.N., Li, B. and Waskett, P.R. (1999). Analytical Design Planning Technique: A model of the detailed building design process. *Design Studies* 20:3, 279-296.
- Ballard, G. (2000). Positive vs Negative Iterations in Design. International Group for Lean Construction, IGLC 8
- Ballard, G. and Koskela, L. (1998). On the agenda of design management research. International group for lean construction. Guaruj, Brazil.
- Ballard, G. and Koskela, L. (2012). Is production outside management? *Building Research and Information*, 40:6, 724-737.
- Bølviken, T., Gullbrekken, B. and Nyseth, K. (2010). Collaborative design management. International Group for Lean Construction. Haifa, Israel.
- Christensen, S. and Kreiner, K. (1991). *Prosjektledelse i løst koblede systemer*. Copenhagen: Jurist- og Økonomiforbundets forlag.
- Cooper, R. G. (2008). Perspective: The Stage-Gate Idea-to-Launch Process - Update, What's New, and NexGen Systems. *The Journal of Product Innovation Management* , 20.
- Cooper, R.G. (1988). The new product process: A decision guide for management. *Journal of Marketing Management*, 3:3, 238-255.
- Kalsaas, B.T. (2012). THE LAST PLANNER SYSTEM STYLE OF PLANNING: ITS BASIS IN LEARNING THEORY. *Journal of Engineering, Project, and Production Management*, 2:2, 88-100.
- Kalsaas (2013). Collaborative innovation: The decade that radically changed drilling performance. *Production planning & control*; 24:2-3, 265-275.
- Kalsaas, Bo Terje and Sacks, Rafael (2011). Conceptualization of interdependency and coordination between construction tasks. In: *Proceedings of the 19th Conference of the International Group for Lean Construction*. University of Salford, 2011, pp. 33-44.

- Kolb, D. A. (1984). *Experiential learning. Experience as the source of learning and development*. Englewood Cliffs, New Jersey: Prentice Hall.
- Koskela, L. (2004). *Making-Do - The Eighth Category of Waste*, Proceedings of the 12th International Group for Lean Construction Conference, Denmark.
- Koskela, L., Ballard, G. and Tanhuanpää, V.-P. (1997). *Towards Lean Design Management*. Proceedings of the fifth annual conference of the International Group for Lean Construction, AU.
- Lukka, K. (2003). *The constructive research approach. Case study research in logistics*. Publications of the Turku School of Economics and Business Administration, Series B1(2003), 83-101.
- Macomber, H. and Bettler, R. (undated, trademark 2011). *Responsibility-based Project Delivery*. Lean Project Consulting, www.leanproject.com.
- Male, S., Bower, D. and Aritua, B. (2007). *Design management: changing the roles of the professions*. *Management, Procurement and Law* p. 78-82.
- PMI (2013). *A Guide to the Project Management Body of Knowledge, Fifth Edition*
- Reason, P. and H. Bradbury (eds.) (2008). *The SAGE Handbook of Action Research (2 edition)*. London: Sage.
- Reinertsen, D.G. (1997). *Managing the design factory: the product developer's toolkit*. New York. Free Press.
- Schwaber, K. and Sutherland, J. (2011). *The Scrum Guide. The Definitive Guide to Scrum: The Rules of the Game*. Scrum.org.
- Simon, H. A. (1996). *The sciences of the artificial*. Cambridge, Massachusetts: MIT press.
- Smith, R.P. and Eppinger, S.D. (1997). *Identifying Controlling Features of Engineering Design Iteration*. *Journal of Management Science*. 43:3, 276-293.
- Thompson, J.D. (1967/2003). *Organizations in Action. Social Science Bases of Administrative Theory*. New York: McGrawhill. [First published in 1967].
- Tryggstad, K. (2012). *Perspectives on Projects, Construction Management and Economics*, 30:5, 416-420.
- Vatn, J. (2008). *Project Risk Analysis*. Trondheim, Norwegian University of Science and Technology.
- Winch, G.M. (2002) *Managing Construction Projects. An Information Processing Approach*, Blackwell Science: Oxford.
- Wysocki, R. K. (2009). *Effective Project Management - Traditional, Agile, Extreme (5. ed.)*. Indianapolis, Indiana: Wiley Publishing, Inc.