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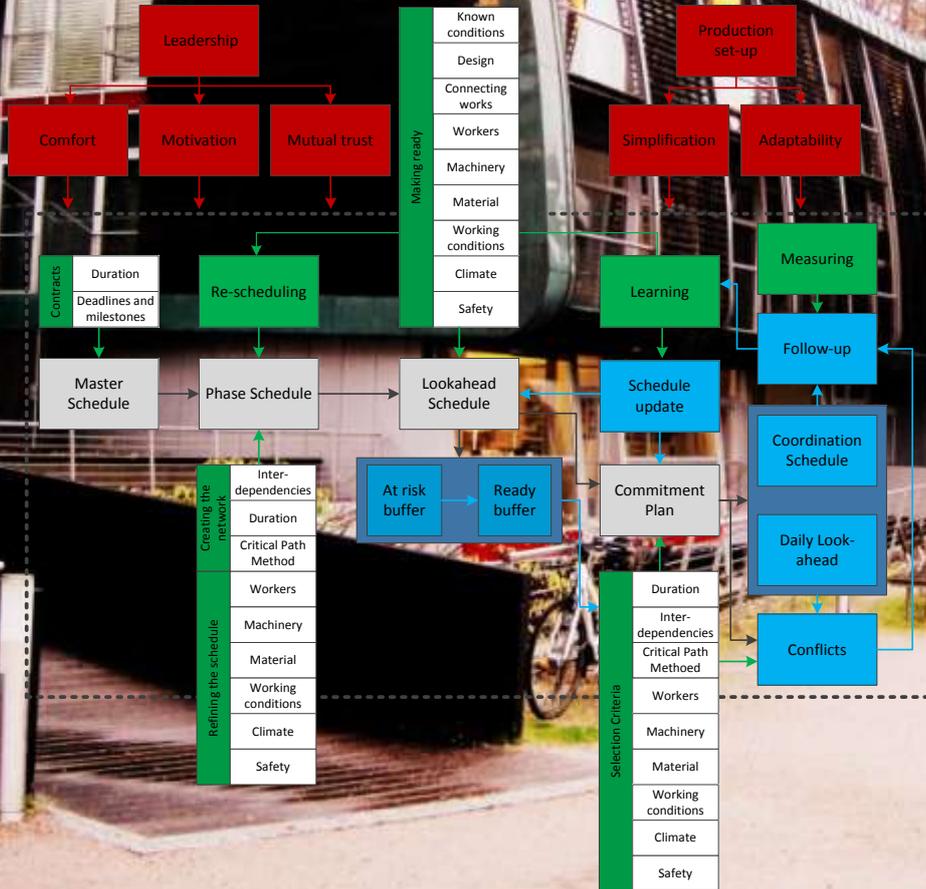
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EXPLORING THE LAST PLANNER SYSTEM IN THE SEARCH FOR EXCELLENCE



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Exploring the Last Planner System in the Search for Excellence

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Included papers:

Paper 1: Lindhard, S. and Wandahl, S., (2011): Handling soundness and quality to Improve Reliability in LPS – A case study of an offshore construction site in Denmark, COBRA International Research Conference.

Paper 2: Lindhard, S. and Wandahl, S., (2012): Scheduling of Large, Complex, and Constrained Construction Projects – An Exploration of LPS Application, International Journal of Project Organisation and Management, in press.

Paper 3: Lindhard, S. and Wandahl, S., (2012): Exploration of Correct LPS Practices in Scheduling of Large, Complex and Constrained Construction Projects, International Journal of Project Organisation and Management, in press.

Paper 4: Lindhard, S. and Wandahl, S., (2012): Improving the Making Ready Process – Exploring the Preconditions to Work Tasks in Construction, Proceedings for the 20th International Group for Lean Construction.

Paper 5: Lindhard, S. and Wandahl, S., (2012): The Robust Schedule – A Link to Improved Workflow, Proceedings for the 20th International Group for Lean Construction.

Paper 6: Lindhard, S. and Wandahl, S., (2012): Adding Production Value with Application of Value Based Scheduling, COBRA International Research Conference.

Paper 7: Lindhard, S., and Wandahl, S., (2012): Designing for Second Generation Value – Future Proofing Constructions, COBRA International Research Conference.

Paper 8: Lindhard, S. and Wandahl, S., (2012): On the Road to Improved Scheduling – Fitting Activities to Capacity, COBRA International Research Conference.

Paper 9: Lindhard, S. and Wandahl, S., (2013): Exploration of Reasons to Non-Completions in Construction, The International Journal of Construction Management, submitted.

Paper 10: Lindhard, S. and Wandahl, S., (2013): Learning from constraints – On the road to increased productivity in on-site production, Construction Management & Economics, accepted, revised paper submitted.

Paper 11: Lindhard, S. and Wandahl, S., (2013): Improving On-site Scheduling: Looking into the Limits of Last Planner System, The Built & Human Environment Review, Vol. 6, pp. 46-60.

Paper 12: Lindhard, S. and Wandahl, S., (2013): On the Road to Improved Scheduling: Reducing the Effects of Variations in Duration, ICCREM 2013: International Conference on Construction and Real Estate Management, accepted.

Paper 13: Lindhard, S. and Wandahl, S., (2013): Looking for Improvements in Last Planner System: Defining Selection Criteria, ICCREM 2013: International Conference on Construction and Real Estate Management, accepted.

This thesis has been submitted for assessment in partial fulfillment of the PhD degree. The thesis is based on the submitted or published scientific papers which are listed above. Parts of the papers are used directly or indirectly in the extended summary of the thesis. As part of the assessment, co-author statements have been made available to the assessment committee and are also available at the Faculty. The thesis is not in its present form acceptable for open publication but only in limited and closed circulation as copyright may not be ensured.

Preface

This thesis is completed at the Department of Mechanical and Manufacturing Engineering, Aalborg University, Denmark. The thesis is submitted to the Faculty of Engineering and Science at Aalborg University in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

The main thesis contains an in-detail description of the research process and the contribution to knowledge and thus serves as documentation for the derived results. It is my hope that the presented thesis can initiate and contribute to a process wherein production control and scheduling of on-site construction can be improved.

I would like to give thanks to all who have helped me in completing this thesis. To all the site-managers who have helped me and let me do observations at their sites, to Glenn Ballard who made a research stay at UC Berkeley as a visiting researcher possible, and supervised me during the stay, and finally to my supervisor Søren Wandahl whose constructive critique helped me in enhancing my scientific level as a researcher.

Søren Munch Lindhard

Abstract

This PhD thesis contains the results of a three year research process carried out at Department of Mechanical and Manufacturing Engineering at Aalborg University. The thesis is entitled “Exploring the Last Planner System in the Search for Excellence” and does together with the appended published papers serve as documentation for the conducted research. The research topic has been scheduling of on-site construction with focus on improving the lean based production control tool Last Planner System (LPS).

The research topic was chosen due to today’s production control systems’ inadequacy of handling the complexity of on-site construction. Today’s production control systems’ inadequacy has resulted in numerous of cost and time overruns. Even though LPS is reported to have a positive effect on schedule reliability, improvements are still possible. Therefore, the current state of LPS has been explored both regarding the theoretical comprehension and the on-site application. To create the theoretical foundation a literature survey was conducted. On-site application was examined through three different studies. 1) A questionnaire survey added to create an appreciation of knowledge to, and application of, LPS in the industry. 2) Four case studies were conducted to increase the richness and depth to the data and thus gain a more colorful insight into production control and scheduling on-site. Archive data of non-completions made it possible to extract quantitative data and to make statistical hypothesis testing. 3) Three interviews with site-managers. The interviews were used to capture the site-managers’ experience, attitudes, and opinions in relation to production control with focus on scheduling.

Based on the collected data, LPS was analyzed. The analysis revealed several points of criticism and suggestions to areas where LPS can be improved. Key critiques to the existing LPS were that it is based on a closed system view, where the surrounding world not is considered, that leadership and motivation of project participants is disregarded, that the Critical Path Method (CPM) is ignored, that there is only a limited interest for flows, that the making ready process not is considering the quality of the fulfillment, that variation in soundness occurs, that LPS does not incite communication and collaboration on-site, and finally that the output quality is not considered in the follow-up phase.

As an answer to the revealed critiques a new framework for production control was developed. By adopting an open system-theory mindset the surrounding world including motivation and leadership is now considered. The surrounding world is important because it affects both processes and behavior on-site which together are having a great impact on the quality and quantity of the output. The existing criteria (duration and interrelationships) for selecting activities have been expanded to include flow and CPM considerations, to increase schedule quality. The making ready process is changed to include both the presents and the quality of the fulfillment. Hence, optimal fulfillment is pursued. A health check of buffered activities is added to handle variation in sound activities and to avoid non-ready activities in entering the Commitment Plans. In the search for improved on-site communication and collaborations a Coordination Schedule is implemented at the Commitment Plan level. Finally, the follow-up phase now includes an evaluation of both output quantity and quality to increase management’s insights to the progress of the construction site. All changes have been evaluated by interviewing seven experts. The experts were interviewed to refine the adjustments and to add validity to the new framework. A full description of the new production control framework can be found in chapter 3 Exploring for excellence within Last Planner System.

Dansk Resumé

Denne Ph.d.-afhandling indeholder resultaterne af tre års forskning. Forskningsforløbet har været tilsluttet Institut for Mekanik og Produktion på Aalborg Universitet. Afhandlingen, som har fået titlen "Exploring the Last Planner System in the Search for Excellence", udgør sammen med de i appendiks vedlagte artikler dokumentation for den udførte forskning. Forskningsemnet har været produktionskontrol og tidsstyring af byggeri, med et fokus på at forbedre det Lean baserede kontrolværktøj Last Planner System (LPS).

Forskningsemnet var valgt på baggrund af nutidens kontrol- og tidsplanlægningsværktøjers utilstrækkelighed i forhold til at håndtere byggepladsens kompleksitet. Denne utilstrækkelighed er en medvirkende faktor til de omkostnings- og tidsmæssige forsinkelser som plager byggebranchen. Til trods for at LPS har haft en positiv effekt på tidsplanens robusthed, er der stadig plads til forbedringer. Med disse forbedringer for øje er LPS undersøgt både i forhold til den teoretiske forståelse samt den praktiske anvendelse. Den teoretiske forståelse for LPS er opnået igennem et litteraturstudie, mens fire case studier er anvendt til at kortlægge den praktiske anvendelse. 1) En spørgeskemaundersøgelse er anvendt til at give indblik i niveauet for viden om og anvendelse af LPS. 2) Fire case studier er gennemført for at få en mere dybdegående viden af LPS'es anvendelse i praksis. Arkiv data fra case studierne omhandlende ikke færdiggjorte aktiviteter har gjort det muligt at foretage statistiske beregninger. 3) Tre interview med byggeledere er afholdt. De tre interviews er anvendt til at fange byggeledernes erfaringer og holdninger i forhold til produktionskontrol, men med fokus på tidsplanlægningen.

Efterfølgende er LPS på baggrund af de indsamlede data blevet analyseret. Resultatet af den udførte analyse er en række kritikpunkter og forslag til, hvor LPS kan forbedres. Nøglepunkter i denne kritik inkluderer som følger: LPS tager udgangspunkt i en lukket systemteori, således er den verden, som LPS agerer i, ikke medtaget; der er set bort fra lederskab og motivation hos projektdeltagerne; Critical Path Method er ikke betragtet, der er en begrænset interesse i flows, klargøringsprocessen medtager ikke kvaliteten af klargøringen; variationer i aktiviteterers sundhed er en realitet; LPS opfordrer ikke til forbedret kommunikation og samarbejde på pladsen samt at opfølgingsfasen ikke tager kvaliteten af outputtet i betragtning.

Med udgangspunkt i de rejste kritikpunkter er et nyt produktionskontrollsystem udviklet. I dette system er anvendt en åben systemteoretisk tilgang, som således inkluderer den omkringliggende kontekst, hvori produktionskontrollsystemet agerer. En del af denne kontekst indbefatter lederskab og motivation, som nu således er overvejet. Det er vigtigt at medtage omverdenen i sine overvejelser, fordi den har indflydelse på både de processer og den adfærd, som er på pladsen, og har derigennem stor indflydelse på både kvaliteten og kvantiteten af outputtet. De nuværende udvælgelseskriterier (varighed og indbyrdes afhængigheder) er blevet udvidet til at indbefatte flow og CPM betragtninger, hvilket er med til at forbedre kvaliteten af tidsplanen. Klargøringsprocessen er ændret til nu også at vurdere kvaliteten af opfyldelsen. Således arbejdes der frem imod optimal opfyldelse. Et ugentligt sundhedstjek af bufferaktiviteterne er inkluderet for at håndtere de ændringer, som opstår i aktiviteterers sundhed og for derigennem at undgå, at ikke sunde aktiviteter bliver flyttet over i Ugeplanerne. For at forbedre kommunikationen og samarbejdet på pladsen er der på ugeplansniveau implementeret en Koordinationsplan. Ydermere er opfølgingsfasen udvidet til at evaluere både kvantiteten og kvaliteten af det udførte arbejde. Dette er valgt for at forbedre byggepladsledelsens indsigt i byggepladsens fremdrift. Alle ændringer er ved at interviewe syv eksperter blevet evalueret. Eksperterne er interviewet for at

forbedre de foreslåede ændringer samt for at øge validiteten er det udviklede produktionskontrollsystem. En uddybet beskrivelse af det nye produktionskontrollsystem kan findes i kapitel 3 Exploring for excellence within Last Planner System.

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1. Introduction

Production control is an essential part of every construction project. Production control is necessary to handle the complexity of the project. Moreover, the construction process is due to production characteristic affected by different unpredictable factors making the constructing process itself complex (Ballard 1998; Bertelsen 2003a; Salem *et al.* 2006; Schmenner 1993). In this complex, dynamic, and uncertain context the schedule is trying to add structure and to create order in an attempt to be able to control and manage the production. Nielsen (2008) explains: *“As long as man has undertaken complicated tasks there has been a need for planning, execution and control.”* As a part of the traditional scheduling process, work tasks are broken down to activities, interdependencies are revealed, and the sequence is determined. The schedule serves as a tool to communicate plans from management to the floor, i.e. the craftsmen executing the plans on-site. Thus, the schedule tells the craftsman of when and where activities need to be conducted.

In construction, scheduling has been proved troublesome. Existing production control tools are unable to fully handle the complex process (Apelgren *et al.* 2005; De Meyer *et al.* 2002). Thus, cost and time overruns are an everyday phenomenon in the construction industry (Abdalla and Battaineh 2002; Al-Momani 2000; De Meyer *et al.* 2002). Several approaches to production control exist but none are fully capable of eliminating the risk of time and cost overruns. The research presented is a three year study of the scheduling approach Last Planner System (LPS) which is a lean based production control tool. Reliability of commitments plays a central role in LPS. Therefore, activities in LPS are through a making-ready process ensured to be completed on schedule. To measure and manage commitments in the schedule, the Percentage Planned Completed (PPC) measurement was implemented. The implementation of LPS did according to Ballard (1999) successfully raise the PPC level from 50 to 70 percent. An enlarged description of LPS can be found in (Lindhard and Wandahl 2012a), where *“State of the Art”* is presented.

Despite the positive *“test”* results in the research studies, the construction industry is still struggling with both cost and time overruns and by following the LPS measurement for scheduling quality (PPC), still 30 percent of all scheduled activities are not completed on schedule. The conclusion is as follows: scheduling of on-site constructions needs to be improved. Since Ballard (2000; 1995) presented the system, the development has been at a standstill; therefore, not much has changed. This despite the perceptible problems; including cost and time overruns, inadequate communication and collaboration, errors, defects and rework, low productivity etc.; which still dominate on-site scheduling indicates that production control needs to be handled differently. As Marcel Proust (1913-27) once stated: *“The real voyage of discovery consists not in seeking new lands but seeing with new eyes.”* These new eyes are open minded they challenge the existing concepts and search for new solutions. The point of departure to the presented research project has been the LPS. With the eyes open, which is in accordance with the Lean philosophy, the research project is searching for continuous improvement, to complete the voyage.

1.1 Structure of the thesis

This thesis is a paper based thesis and does therefore consist of two distinct parts, respectively the cover and the papers. The first part is the cover. Briefly, the cover contains a summarized description of the research hypothesis, research design, scientific approach, methodologies, the framework to the revised production control tool, and ending with a final conclusion. The second part of the thesis is the appended

papers. This part consists of 13 peer reviewed papers whereof 5 are journals and 8 are conference papers. The appended papers uncover the extend and relevance of the working hypothesis presented in section 1.3 and reveal several areas for possible improvement. The framework presented in chapter 3 is based on a compilation of the findings presented in the papers. The cover does not repeat the work published in the appended papers but instead the findings and contributions from the papers are included when relevant. Thus, only the final results are presented in the thesis, the means to reach the results including “state of the art”, analysis etc. can be found in the respective papers. An elaboration of the individual paper’s contribution (analysis, exploratory, and syntheses) can be found in Table 1 while a description of the key-findings can be found in section 1.4.

1.2 Definitions

To create a lucid and mutual understanding to the terminology used in the thesis, definitions and explanations to obscure terms are presented in this section.

Activity vs. task: An activity is understood as the individual work actions completed at a defined location while tasks are understood as a cluster of activities completed at multiple locations (Kenley and Seppänen 2009).

Flexible vs. inflexible activities (buffer): Flexibility is referring to the ability to change. Hence, inflexible activities are tied to the sequence while flexible activities have free slack and can therefore be moved to make adjustments to the current situation. An elaboration can be found in Lindhard and Wandahl (2012b).

Reliability vs. Robustness: Reliability is expressing a likelihood of obeying; thus, to the degree something can be depended on or be trusted at. Thus, increased schedule robustness leads to increased schedule reliability (Summers 2009). Robustness is referring the ability to deal with variation; thus, to the degree elements in a system can be changed without collapsing the system (Summers 2009). Thus, a robust production control system is capable of absorbing variation.

Efficiency vs. effectiveness: Efficiency is in general defined as doing things right (Wandahl 2004). By keeping a closed system view and not regarding the external environment “output” is gained by improving the scheduling itself (internal processes). Effectiveness is defined as ensuring that the right things are done (Wandahl 2004). Improvements are achieved by improving the outer context (external processes) wherein the schedule takes action.

Production control vs. scheduling vs. planning: As the word production control is indicating, production control is regarding control of the production. Production control includes all the planning and scheduling processes which is initiated to achieve production control. Planning is referring to the process of considerations and deciding on a plan (Summers 2009). Afterwards the plan can be followed. Scheduling is referring to the process of deciding the where and when an activity is completed (Summers 2009). Afterwards the decided schedule composes a plan which can be followed.

Production system (capacity): The capacity of the production system is according to the Lean-philosophy equal to the sum of work and waste (Ohno 1988). Lindhard and Wandahl (2012c) find that “*Waste is not to fully utilize of the capabilities and possibilities in the production system.*” Moreover, Lindhard and Wandahl (2012c) state that a central part of the production system is the present workforce which drives the

progress. Improving the skills of the workforce adds knowledge and expands the capacity, while improving the motivation increases the utilization of capabilities already existing in the production system (Lindhard and Wandahl 2012c).

System vs. framework: In this thesis, system is used to describe the internal structure in the developed framework to ensure project control. Thus, while control system is referring to the internal processes in the developed system, framework is referring to the entire system which includes the external view. The external view contains the outside elements which affect the system and creates the outer context wherein the control system acts.

1.3 Working Hypothesis

The objective of the PhD project is to improve the production control processes of on-site construction; this includes both efficiency and effectiveness. Efficiency is achieved by improving the schedule itself for instance by improving schedule reliability or quality and by improving or simplifying the appertaining process to releasing resources and decreasing time usage. Effectiveness is achieved by improving the process and flows outside the schedule and is resulting in increased productivity. The research project is taking its outset in the Lean Construction production control tool Last Planner System (LPS). LPS has an intense focus on schedule reliability, which according to LPS theory successfully has been raised (Ballard 1999). Moreover, LPS theory believes that improved reliability leads to improved productivity at the construction site. This tendency has been documented by a numerous of studies which indicate this relationship (Alarcón *et al.* 2005; Alsehaimi *et al.* 2009; Ballard 2000; 1999; Formoso and Moura 2009; Friblick *et al.* 2009; Garza *et al.* 2000).

As mentioned in the introduction section, LPS has raised the PPC level to around the 70 % level. This entails that 30 % of all scheduled activities are not completed according to the schedule. Therefore, only focusing on schedule reliability, in accordance to LPS theory, there is still a large potential for improvement (Ballard 2000). Despite the potential for improvement there exists only very little critique of LPS, this could be the reason why the schedule reliability is right now stuck at the 70 % level (Ballard 1999). It is important to point out that the PPC measurement does only measure scheduling quality and not productivity. For instance, completed but non-scheduled activities are not included in the measurement. In the search of excellence, this PhD-project is looking into on-site production control but with a focus on LPS. This has been done through the following research hypothesis:

Production control in on-site construction can be improved; this can be achieved by improving the efficiency and effectiveness of LPS.

During the research process eyes are continuously kept open for critical elements and areas with extra potential. The identified critical elements compose the specific problems which are addressed in order to improve the efficiency and effectiveness of on-site production control.

1.3.1 Research Objectives

The primary research objective is to increase schedule efficiency and effectiveness for thereby increasing on-site productivity. In the search for an improved schedule, focus is on learning to continuously improve

both scheduling and coordination. Today learning is in LPS achieved by identifying and eliminating root-causes. Moreover, an objective is to ensure that the schedules provide guidance and overview and support decision making in making faster and more proactive decisions and simultaneously increasing the probability in making the most appropriate decision, especially in stress situations. The purpose is to prevent the impact of the negative and increase the impact of the positive occurrences. Another objective is to secure a constant and high flow in the constructing process and; thus, avoid interruptions in the flow. Keeping a constant and high flow is important in an attempt to increase utilization of on-site capabilities and on-site productivity. The effect of a constant and high flow will be to avoid time overruns caused by interruptions in the production. In relation to the flow considerations it is a request to increase the focus on output quality. Poor quality will, because of the related rework, spoil the positive effects of a constant and high flow of work, and will induce both cost and time overruns. Finally, one research objective is to increase schedule robustness. A more robust schedule enhances the probability of observance of the budget, time schedule etc. and gives a more controllable construction project.

1.3.2 Delimitation

Delimitations in research are important to ensure a well defined research focus and objectives. This study covers on-site production control of construction projects. Thus, only the execution phase is considered. Moreover, this study is limited to concern only LPS. The theoretical considerations and ideology behind LPS are together with practical application examined, and weaknesses are identified. The presented research is delimited to not include economical considerations even though the subjects are slightly interrelated. Instead an open-system theory is applied where topics from outside the focus are included when relevant. In this way, only relevant topics which directly influence production control are included. Site-management's application of production control system has, because LPS is a site-management tool, had the main attention. Hence, the outcome of the study is directed to site management. Site management is considered to have the primary responsibility for implementing and daily operation of the system.

1.4 Published Papers

The thesis is based on a collection of published papers. These papers are constituted of peer reviewed published conference or journal papers which together document the scientific contribution in the PhD project. Furthermore, the published papers do follow the flow of the study and creates an understanding of how the research project has developed. In the following each paper is shortly introduced and the scientific contribution is outlined. The presented papers uncover several areas wherein on-site production control can be improved; cf. the working hypothesis presented in section 1.3. Theoretically and practically application of LPS has been examined in the attempt to look for possibilities for improvement in both the efficiency and effectiveness. Possibilities for improvement have been revealed and several points of criticism have been raised to the existing production control system. The whole papers including publication details can be found in Appendix A at the back of the thesis.

Lindhard, S. and Wandahl, S., (2011): Handling soundness and quality to Improve Reliability in LPS – A Case Study of an Offshore Construction Site in Denmark, COBRA International Research Conference, (contribution 90%)

- Preconditions have a changing nature, it is critical since it can change the soundness of both buffered and scheduled activities. To minimize the risk of non-sound activities in the Weekly Work

Plans it is proposed to implement a weekly health check. Detecting changes in preconditions before completing the Weekly Work Plans increases the robustness of the schedule.

- LPS focuses only on the schedule and its reliability, not on the product and its quality. If quality is not taken into account it gives a disfigured picture of the performance, c.f. the PPC measurement. To restore the picture poor quality and related defects should be deducted from the performance. Quality can be detected by a judgment of the construction manager or by registering rework.

Lindhard, S. and Wandahl, S., (2012): Scheduling of Large, Complex, and Constrained Construction Projects – An Exploration of LPS Application, International Journal of Project Organisation and Management, in press, (contribution 90%)

- Implementation of LPS has not fully occurred. Often parts are omitted, for instance the PPC-measurement, the seven preconditions, buffering, Phase Scheduling and Just-In-Time delivery are often ignored. A partly applied LPS can be a main barrier to increased reliability in the scheduling process.
- Root-causes to failures can often be traced back to the Look-ahead Plan, where the problems are overlooked. This underlines the importance of practical knowledge, and once again states why practitioners such as foremen shall be a part of the making ready process.

Lindhard, S. and Wandahl, S., (2012): Exploration of Correct LPS Practices in Scheduling of Large, Complex and Constrained Construction Projects, International Journal of Project Organisation and Management, in press, (contribution 90%)

- LPS still faces implementation challenges; to overcome these challenges especially two factors have been found important: willingness to succeed and knowledge. Knowledge is important to secure a correct implemented and applied system, while willingness or stubbornness is important to maintain and anchor changes deep into the organizational behavior.

Lindhard, S. and Wandahl, S., (2012): Improving the Making Ready Process – Exploring the Preconditions to Work Tasks in Construction, Proceedings for the 20th International Group for Lean Construction, (contribution 90%)

- All preconditions need to be identified to create awareness and to secure that activities actually are made sound during the making ready process. The construction design category is expanded to also contain conditions caused by site management. Moreover, it was found that the external condition category, from the traditional seven preconditions is covering several fundamental different subcategories. Therefore, the external condition category is divided into three new categories:
- *“Climate conditions must be acceptable. The preconditions focus on external environmental effects such as rain, snow, wind, heat, cold etc.”*
- *“Safe working conditions must be present. The national “Health and Safety at Work Act” has to be obeyed to keep the employees safe.”*
- *“The surrounding conditions must be known. The precondition focuses on securing that existing conditions, if necessary, are examined. Problems often arise during excavations or refurbishment assignments.”*

- Activities shall be made ready for completion. By stating completion it is not enough to secure an activity can be started.

Lindhard, S. and Wandahl, S., (2012): The Robust Schedule – A Link to Improved Workflow, Proceedings for the 20th International Group for Lean Construction, (contribution 90%)

- A too tight schedule leads to conflicts and increased cost, while a too loose schedule results in unnecessary waste of time and increased cost. Therefore, as a general guidance, the timeframe should fit the individual project. But the deadline should be flexible instead of fixed. By introducing flexibility into the timeframe negotiations between contractor and client should help creating win/win situations in the attempt to bring both productivity and value creation up.
- In the T-F-V theory, time is considered waste. Even though extra time overall might have a positive effect on productivity and cost. Therefore, a more nuanced picture of time is needed. Even though time is waste, wisely determined extra time can be necessary waste on the road to excellence in construction. Furthermore, extra time will increase the robustness of the schedule.

Lindhard, S., Wandahl, S., (2012): Adding Production Value with Application of Value Based Scheduling, COBRA International Research Conference, (contribution 90%)

- Improving human motivation is increasing the exploitation of capabilities already in the production system and is thus minimizing waste. Capabilities and utilization are generally important; therefore, the phrase can be generalized to: *“Waste is not to fully utilize of the capabilities and possibilities in the production system”*. This theorem should be regarded as the eighth source to waste.
- In Value Based Scheduling (VBS) values form an ethical guideline supporting on-site behavior. VBS is focusing on leadership and the connected process values which guides and supports the transformation process to increase comfort, and trust between the projects participants. The output is increased motivation, dedication, accountability, and collaboration, which is increasing the probability of schedule observance.

Lindhard, S., and Wandahl, S., (2012): Designing for Second Generation Value – Future Proofing Constructions, COBRA International Research Conference, (contribution 90%)

- During a building’s design-phase it must be taken into consideration that users and even owner at some point will change. Thus in order to future proof the building it has to fulfill the needs of the 2nd, 3rd... and the nnd generation owner. Value is preserved in the building by securing that the building is fully utilized and that it fulfills the owner’s needs.
- Capturing future needs is achieved by making the owner conduct a *“lifecycle”* plan of his expectations to the future usage of the building in its lifetime.
- The key is to design the building as flexible and transformable as possible. Flexibility is defined as the ability to change the constructional usage without needing to make constructional changes; while two different types of transformability is defined a) the ability to transform the existing structure in order to adapt to the changing environment and b) the ability to add structures to the existing structure.
- Changes in needs and usage have an impact already in the construction phase and result in a changed design. The scheduling tool needs to be able to handle these changes without affecting

the workflow. When handling changes, communication and collaboration is essential, because: “It takes teamwork to work around the changes to find and exploit new possibility and to optimize the process”

Lindhard, S. and Wandahl, S., (2012): On the Road to Improved Scheduling – Fitting Activities to Capacity, COBRA International Research Conference, (contribution 90%)

- Congestions in the making ready process shall be avoided to secure that the making ready process continuously can feed the Weekly Work Plan with sound work. To keep a high work flow, activities should be fit to capacity. Lowering the manning slows down the production and should be avoided. Multiple initiatives exist which reduces the risk of congestions:
- A) Simplifying the production. A more simple process can be achieved by reducing the number of activities and trades on-site. Technical and specialized parts of the production can be moved away from the construction site which reduces the on-site production to a simple assembly process and thereby reduces the need for specialized craftsmen on-site. Reduced needs for a specialized workforce can create a breeding ground for more adaptable work crews which ideologically can span several trades.
- B) Increasing flexibility in both the process and in tasks. Flexibility looses the interdependencies between subcontractors. Flexibility in tasks can be achieved by a flexible workforce, for instance by applying multi-skilled crews or overtime while flexibility in the process can be achieved by applying buffers. Traditional buffering should be supplemented with flexible buffer activities. Flexible buffer activities can be conducted without regarding the sequence because they, opposite inflexible activities, are not tight into the sequence. Thus, flexible buffer activities can be stored until needed.
- C) Creating adaptability in the production, thus improving the ability to adapt to unforeseen changes in the production. Focus is on removing waste such as unproductive time in the adaption process. Adaptability is increased by increasing flexibility.

Lindhard, S. and Wandahl, S., (2013): Exploration of Reasons to Non-Completions in Construction, The International Journal of Construction Management, submitted, (contribution 90%)

- Six high-frequent causes to non-completions were revealed: connecting work, changes in work plans, workforce, weather conditions, material, and construction design.
- Five low frequent causes to non-completions were revealed: space, equipment, rework, unexpected conditions, and safety.
- Non-completions did together with a complex and changing environment force the schedule to be rethought. Even though changes were made to optimize throughput, site-mangers have to be aware of the associated negative effects when making schedule changes. Associated negative effects include confusion, misunderstandings, and loss of the schedule’s creditability. Too many schedule changes will affect how the schedule is perceived where a commitment no longer is perceived binding but only guiding. In worst case, contractors start to neglect the project’s plans and instead work towards own priorities.

Lindhard, S. and Wandahl, S., (2013): Learning from constraints – On the road to increased productivity in on-site production, Construction Management & Economics, accepted, revised paper submitted, (contribution 90%)

- Construction design, cf. the seven preconditions, was often causing constraints at site. The constraints could indicate a need for an improved communication and collaboration between the design and execution units, and between the different trades on-site. By improving communication and collaboration these processes could be integrated as one interconnected process instead of as today be consisting of many autonomous processes.
- In construction, delays are easily transmitted from one activity to another. The observed magnitude of the effect indicates, what previous research has shown, namely, that an adequate buffer size only very rarely is applied in construction.
- Comparing results between on-site observations and questionnaire respondents showed a general tendency to overestimate the frequency of constraints related to equipment, materials, and space. The wrong perceptions could be related to how these occurrences are experienced. Future research has to explain why.

Lindhard, S. and Wandahl, S., (2013): Improving On-site Scheduling: Looking into the Limits of Last Planner System, The Built & Human Environment Review, Vol. 6 pp. 46-60, (contribution 90%)

- The limits of LPS were throughout an in-depth analysis revealed. Most interesting findings were: That LPS does not incite communication and collaboration on-site, that the surrounding world is not considered, that leadership and motivation of project participants are disregarded, that the Critical Path Method (CPM) is ignored and finally that there is only a limited interest for flows.
- Including CPM and flow consideration in the schedules will improve the sequencing of activities. Therefore, additional selection criteria need to be developed.

Lindhard, S. and Wandahl, S., (2013): On the Road to Improved Scheduling: Reducing the Effects of Variations in Duration, ICCREM 2013: International Conference on Construction and Real Estate Management, accepted, (contribution 90%)

- Both positive and negative variation in completion time is an unbidden element in on-site construction. Negative variation does directly result in delay, while positive variation normally creates unexploited gaps between activities and thus unexploited capacity.
- Negative variation is reduced if activities are ensured ready at the time of completions, thus root causes to non-completions must be found and eliminated. Moreover, if the making ready process was seeking towards optimal production conditions the risk of negative variation is reduced.
- Positive variation could be reduced by ensuring that a crew finishing an activity too early can continue their work and moreover, that any connecting activities are able to start as fast as possible.

Lindhard, S. and Wandahl, S., (2013): Looking for Improvements in Last Planner System: Defining Selection Criteria, ICCREM 2013: International Conference on Construction and Real Estate Management, accepted, (contribution 90%)

- Six flows are identified as relevant when selecting activities to the schedules: workforce, material, and machinery which comprise the needed resources and safety, climate conditions, and space which affect the pace of the work.
- The output of the analysis is a list of recommendations of how to refine the schedules by including the six flows in both the Phase Scheduling, the Look-ahead, and the Commitment level.

2. Research Design

The conducted research is based on scientific presumptions, which affect how data is collected and perceived. The scientific presumptions affect the choice of methods and the structure of the research. Thus, in order to understand the results of this research, consensus of the predefined presumptions which have guided the research needs to be ensured and is therefore presented in this chapter. The clarification includes structure of the research design, the applied scientific paradigm, the applied research methods, and the applied techniques to ensure trustworthiness of the data.

2.1 Structure of Research Design

The PhD-project is composed by six sub-phases. The sub-phases create a chronological overview of the stages the research project is going through. By systematically following and completing all six stages a clear focus is maintained and clear and achievable deadlines are created. The six sub-phases are as follows:

- 1) Confirm that there are problems due to planning
- 2) Literature review of LPS
- 3) Data collection
- 4) Analysis of collected data
- 5) New ways of planning
- 6) Final results and conclusion, accumulation of knowledge

In step 1 problems related to on-site production control are confirmed. The step comprises the preliminaries to the research by visualizing the extent and complexity of the problems in on-site production control. Confirming that problems occur, with today's on-site production control, is a necessary part of confirming the working hypothesis (see, section 1.3) stating that production control in construction can be improved by improving LPS. To gain a broad insight to LPS and to create a theoretical foundation for future research a thorough literature survey is conducted in step 2. The theoretical foundation created by the literature survey creates an understanding to the "state of the art" within the Lean construction and LPS research fields. Parts of the literature survey have been published; thus, elaborations of LPS theory can be found in (Lindhard and Wandahl 2012a) while an elaboration of Lean Construction theory can be found in (Lindhard and Wandahl 2012d). Through the literature survey eyes are kept open for critical elements, and areas with extra potential. These critical elements compose the specific problems which have increased focus in the data collection. In step 3, data is collected. Practical LPS application is observed; moreover, the critical elements discovered during the literature survey are examined. Step 4 contains an analysis of the in step 3 collected data. During this step all critical elements are reviewed and it is determined where LPS can be improved, cf. the working hypothesis. Based on the critiques to LPS, new ways of production control is determined in step 5 which afterwards is validated by experts. Step 6 contains the closing and concluding remarks and suggestions for further research.

By systematically following the six steps, a clear research scope is maintained. Moreover, the sub-steps serve as deadlines created to gain a foreseeable research process. Based on a deductive thinking the first part of the research has a focus on confirming the hypothesis stated in section 1.3. The hypothesis is split

into two parts: 1) confirming that production control in on-site construction can be improved (confirmed at step 1) and 2) Improvements are possible by improving the efficiency and effectiveness of LPS (confirmed at step 2, 3 and 4). The second part of the research is based on an inductive thinking where the objective is to reveal how improved efficiency and effectiveness can be achieved (step 3 and 4). Based on the findings a new framework for production control is developed and validated (step 5), which is followed by a final accumulation of knowledge and a conclusion on the findings (step 6).

The in- and output in the six stages including Ph.D. courses, stays abroad, own empirical studies, and papers is shown in Table 1. In the table the papers are, depending on their contribution, categorized into analysis (examination to increase understanding) exploratory (exploring to learn and discover) and syntheses (combining the lessons learned to create a new framework).

Table 1: In- and output in the six stages of the Ph.D. project.

Stage	Input		Output
	Courses	Empirical study	
Stage 1 <hr/> Confirming problem	- Writing and review (3,75 ects) - Professional communication (2,5 ects) - Classic Organization Theory (5 ects)	Pilot case study	<u>Conference paper:</u> Handling soundness and quality to Improve Reliability in LPS – A case study of an offshore construction site in Denmark <u>Categorization:</u> Analysis <u>Objective/ Research question:</u> Proving that defects and errors are a fact in on-site construction.
Stage 2 <hr/> Literature review	- Introduction to research designs in organisation and management research (4 ects)	Literature survey	<u>Working paper:</u> Literature survey of LPS <u>Categorization:</u> Analysis <u>Objective/ Research question:</u> Create a theoretical foundation to the research field. Non-publication: Parts used when relevant in published papers. Not appended to the thesis.
Stage 3 <hr/> Data collection	- Qualitative research techniques (5 ects)	Questionnaire Case study Interviews	<u>Journal paper:</u> Scheduling of Large, Complex, and Constrained Construction Projects – An Exploration of LPS Application <u>Categorization:</u> Analysis <u>Objective/ Research question:</u> How well is LPS adopted and applied in the Danish construction industry? <u>Journal Paper:</u> Exploration of Correct LPS Practices in Scheduling of Large, Complex and Constrained Construction Projects <u>Categorization:</u> Analysis <u>Objective/ Research question:</u> How does application of the applied elements of LPS correspond to theory?
Stage 4 <hr/>	- Study abroad at UC Berkeley		<u>Conference paper:</u> Improving the Making Ready Process – Exploring the Preconditions to Work

<p>Analysis of collected data</p>	<p>- Lean application</p>		<p>Tasks in Construction</p> <p><u>Categorization:</u> Analysis</p> <p><u>Objective/ Research question:</u> What are the preconditions to the conduction of construction activities in on-site production?</p> <p><u>Conference paper:</u></p> <p>The Robust Schedule – A Link to Improved Workflow</p> <p><u>Categorization:</u> Analysis</p> <p><u>Objective/ Research question:</u> What happens to a construction project if more time is released? And could “win/win” situations be gained if more focus, with time consumption in mind, is on securing a more optimal process?</p> <p><u>Conference paper:</u></p> <p>Adding Production Value With Application of Value Based Scheduling</p> <p><u>Categorization:</u> Exploratory</p> <p><u>Objective/ Research question:</u> Which values could be combined with existing scheduling procedures of on-site construction and how can these values support Last Planner System?</p> <p><u>Journal paper:</u></p> <p>Exploration of Reasons to Non-Completions in Construction</p> <p><u>Categorization:</u> Analysis</p> <p><u>Objective/ Research question:</u> What are the reasons for non-completion of activities in construction?</p> <p><u>Journal paper:</u></p> <p>Learning from constraints – On the road to increased productivity in on-site production</p> <p><u>Categorization:</u> Analysis</p> <p><u>Objective/ Research question:</u> How frequent do recurred constraints lead to non-completions, and how are the failures distributed between the seven preconditions?</p> <p><u>Conference paper:</u></p> <p>Designing for Second Generation Value – Future Proofing Constructions</p> <p><u>Categorization:</u> Exploratory</p> <p><u>Objective/ Research question:</u> How do we handle the changing needs of the customer and how can we increase the constructional transformability to make the constructions fit to current needs?</p> <p><u>Conference paper:</u></p> <p>On the Road to Improved Scheduling – Fitting Activities to Capacity</p> <p><u>Categorization:</u> Exploratory</p> <p><u>Objective/ Research question:</u> How can the complexity of the making ready process be decreased in order to fit activities to capacity to create a (continuous and) resistant workflow?</p> <p><u>Journal paper:</u></p> <p>Improving On-site Scheduling – Looking Into the Limits of Last Planner System</p> <p><u>Categorization:</u> Syntheses</p>
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			<u>Objective/ Research question:</u> Can LPS be further improved? And what are the benefits and shortcomings of the current LPS scheduling methodology?
Stage 5	- Academic Writing in English for PhD Students (2 ects) - Theories of new organizational forms (5 ects)		<u>Conference paper:</u> On the Road to Improved Scheduling: Increasing Schedule Robustness <u>Categorization:</u> Exploratory <u>Objective/ Research question:</u> Looking into how schedule reliability can be improved by handling positive and negative variation <u>Conference paper:</u> A New Approach to Scheduling: Defining Selection Criteria <u>Categorization:</u> Syntheses <u>Objective/ Research question:</u> Establish a set of recommendations of how flow considerations can be included when selecting activities.
Stage 6		Interviews	<u>Cover to PhD. thesis</u> Exploring the Last Planner System in the Search for Excellence <u>Categorization:</u> Syntheses <u>Objective/ Research hypothesis:</u> Production control in on-site construction can be improved; this can be achieved by improving the efficiency and effectiveness of LPS.
From:	Final conclusions and accumulation of knowledge		

2.2 Scientific paradigm

One important aspect of the research design is the scientific paradigm. The applied scientific paradigm represents the researcher's basic beliefs (Guba and Lincoln 1994). These basic beliefs are comprised by stated laws, values, theoretical assumptions, and techniques or standards to its application which are adapted by the researcher (Chalmers 1982; Kuhn 1977). Definitions and understandings to the different paradigms are according to Wainwright (1997) ambiguous. Wainwright's statement is supported by Halfpenny (Halfpenny 1982) who identifies 12 varieties of positivism. Because of the obscurity in the definitions of paradigms, my apprehension to the used paradigms is explained in the following.

As a researcher I do in general have a positivist view on the world. I believe in a real world, that construction sites are real, that problems are real and measurable, that production control is a problem in on-site construction, and that it can be improved. In this concrete and measurable reality the research study has been carried out. Despite the positivistic world view, the scientific research paradigm to the research has a mixed approach with a combination between the positivist, the postpositivist and the critical theory perspective and is depending on the research methods. The research study consists of three major research methods: 1) a questionnaire survey, 2) case studies, and 3) interviews. 1) The questionnaire survey is a quantitative study, and is based on the positivist perspective. 2) The case studies are mainly a qualitative study; however, it has been possible to extract quantitative data related to the on-time completion of scheduled activities. Both the quantitative and the qualitative part of the case studies have had, cf. Yin (1993) and Tellis (1997), a descriptive approach based on respectively the positivist and the postpositivistic perspective. 3) The interviews have been a qualitative study based on the critical theory perspective.

The research paradigm consists of three sub-elements: ontology, epistemology, and methodology (Guba 1990). Ontology is the perception of reality, which in the positivist paradigm has been the realist perspective, in the postpositivistic critical realism, and in the critical theory paradigm the historical realism

perspective. In the realist perspective reality can be measured and is independent of the observer's perceptions; thus, truth can be identified by explaining the relationship between causes and effects. Thus, reality exists and is independent of the individual's appreciation of the (social) world (Burrell and Morgan 1979). Responses in the questionnaire survey and the quantitative data from the case studies are viewed as reflecting reality, a reality which can be measured and analyzed.

Critical realism does likewise realism agree to that reality exists. But opposite realism, critical realism does only believe that an imperfectly reality can be apprehended; this because the world is viewed as intractable and the human mind is viewed as limited and flawed (Guba and Lincoln 1994). Thus, reality is affected by the researcher's values and emotions (Nygaard 2005). This limits the objectivity of the researcher. The fact that the observer's values and motions can influence the observations is exactly why the qualitative part of the case studies is combined with the postpositivist paradigm. The qualitative study includes on-site observations of how LPS is applied on construction site and what problems are faced. Observations are regarded as real, but in accordance with the postpositivistic paradigm it is acknowledged that observations can be influenced by the observer's perception of the situation or the object observed. However, how LPS is observed applied is how this research believes it has been applied during the entire construction period. Observed problems are regarded as real problems occurring at the construction site. Because observations only have taken place at a limited time, and the fact that observations depend on the observer and where he points his attention, the observed problems are not regarded exhaustive. Despite the limited number of cases and observations, both the observed application and problems have been generalized and thus regarded prevailing and relevant to the entire industry.

In the historical realism perspective reality is understood as shaped by multiple of social, political, cultural, economical, ethical, and gender factors (Guba and Lincoln 1994). Thus, the human perception of the world cannot be separated from these factors (Nygaard 2005). Therefore, it is essential to be critical to the collected data. Opinions and statements captured through the interviews are viewed as the respondent's interpretation of the world which constitutes their reality. According to Krauss (2005) meanings are cognitive categories wherefrom the view on reality and the related actions are defined. Meanings are generated and enriched through life experiences, while meanings simultaneously describe, define, justify, and guide the experiences (Chen 2001; Lofland and Lofland 1996). Thus, the respondent's opinions are subjective, they are generated through own experience, e.g. company culture, social and political values and norms which comprises their historical reality. Two sessions of interviews have been conducted. The first interview session was regarding application of LPS and experienced problems in relation to scheduling with the purpose to collect critiques and to reveal areas which could be improved. In the second interview session expert opinions to a developed framework was of interest to improve and verify the framework.

Epistemology is a term for exploring and explaining the knowing and the known (Ferrier 1854). Through epistemology the origin, nature, and limits to human knowledge are investigated. Ferrier (1854) explains the importance of epistemology: *"we are scarcely in a position to say what is, unless we have at least attempted to know what is; and we are certainly not in a position to know what is, until we have thoroughly examined and resolved the question – What is the meaning of to know? What is knowledge? What is knowing and the known?"* Hence, it is necessary to thoroughly consider epistemology before ontology and the conception of reality makes sense (Ferrier 1854).

Positivist epistemology is explaining and understanding the world as based on laws and patterns (Burrell and Morgan 1979; Tuli 2010). Research is carried out without effecting or influencing the outcomes, thus the findings are believed to be a correct picture of the truth (Guba and Lincoln 1994). Postpositivistic epistemology is basically identical with the positivist epistemology with the exception that postpositivism believes that only an imperfect reality is obtainable. Objectivity in the research is restricted because the research itself is affecting and influencing the outcomes; wherefore findings are only probably true (Guba and Lincoln 1994). Critical theory epistemology is subjective. According to Guba and Lincoln (1989) the following question has to be posed: "What is the relationship to the knower and the known?" which according to Smith (1983) should be interconnected and trusting. Knowledge is apprehended through a dynamic inquiry based on dialog where "false" findings are separating from "real" findings (Nygaard 2005). Because of the interactions between the observer and the "object" observed the findings are value mediated (Guba and Lincoln 1994).

Methodology is the means to acquiring knowledge. It is important to distinguish methodology from methods. According to Wainwright (1997): "*methodology involves a philosophical analysis of research strategies whereas method refers to the techniques used to gather data.*" Positivist methodology is based on experiments and often hypothesis which are verified through a quantitative study. Postpositivist methodology is also based on experiments but not necessary as controlled as in the positivist perspective, thus qualitative research such as observations is often applied. Even though postpositivist research most often is concerning falsifications of a hypothesis, the case studies are applied to verify that LPS can be improved. Critical theory methodology is based on a dialog between the observer and the object observed where the objective is to transform misapprehensions and ignorance into consciousness (Guba and Lincoln 1994). Regarding the interviews, the purpose has been to collect and apprehend the various experience and opinions from the respondents and not to transform them.

2.3 Research methods

Research methods refer to the applied research techniques i.e. how research is carried out and how knowledge is discovered (Wainwright 1997). The research project is composed by four main research elements: A systematic literature review of LPS, a questionnaire survey, 4 case studies and two interview sessions of respectively 3 and 7 semi-structured interviews. The four different elements are used to capture both the theoretical and practical aspects of LPS and its application.

During the literature review important theory is gathered and studied, this gives an understanding to the ideas behind the system and increases the knowledge to the system itself. Thus, it comprises the theoretical foundation throughout the research study. Moreover, the case study is a part of a published paper, see Lindhard and Wandahl (2012a), wherein an in-depth description of the method to the literature study also can be found.

The questionnaire survey was applied to capture quantitative data of practitioners' at different organizational levels with different experience, knowledge and attitudes towards LPS. Questionnaire surveys are dominated by a low response rate, but the low response rate is easily counterbalanced with the fact that the questionnaire form can be reused to an unlimited amount of persons. Answers follow predefined intervals which makes it easy to compare and analyze results. Parts of the questionnaire are

used in the paper Lindhard and Wandahl (2012a), in this an in-depth description of the questionnaire survey can be found.

Four case studies were followed to collect qualitative data of LPS application. By following actual construction cases, the detail level of the data was increased and helped in understanding how LPS practically was applied and how it interplayed with the surrounding world. Moreover, following all individual work tasks on-site helped collecting quantitative data. As the construction project preceded all sub-process, including the individual work tasks, could be followed enabling the collection of quantitative data. Moreover, the direct observations were supplemented with unstructured and semi-structured interviews which are crucial in field research (Burgess 1982). Interviews can be used to capture concealed or implicit knowledge, experiences or attitudes which help in understanding the world (Ritchie *et al.* 2005). To avoid being overwhelmed by the almost unlimited amount of data that a case can provide it is important to preserve the research focus throughout the case studies (Eisenhardt 1989; Mintzberg 1979). A description of the methods and the four cases can be found in (Lindhard and Wandahl 2013a) while the methods to the three interviews can be found in (Lindhard and Wandahl 2012d).

Based on all the gathered data, both empirical and theoretical, different aspects of LPS were analyzed. Throughout the analysis both strengths and weaknesses were identified. In the name of continuous improvement, the weaknesses did form the foundation in critiquing the existing system and arguing for changing central parts of the system.

2.3.1 *Evaluation of the refined LPS*

The refined version of LPS has been evaluated by experts. Since the methods are not described in any papers the detail-level in the following presentation is increased. The purpose of making experts evaluate the production control system has been A) to collect input to additional adjustments and to refine the system and B) verification where the experts' credits and criticisms are incorporated to strengthen and to add validity to the revised production control system.

A qualitative research approach was selected to verify the quality of the refined version of LPS. Through email correspondences seven experts were selected for later interviews. The objective of the interviews was primarily to get an expert opinion on the refined version of LPS and to get feedback to improve the developed concept. To get every expert's individual opinion, the interviews were conducted as "face to face" interviews. To ensure high quality of the data, it was ensured that the respondents had experience with production control, scheduling, and in particular with LPS. Moreover, respondents with different background and experience were selected to capture a broader spectrum of opinions and approaches to production control. Of the seven experts one was a Lean consultant, three were site-managers, two were project managers, and one was a client advisor. The respondents are in the description of the production control system made anonymous, where (R1), (R2), (R3), (R4), (R5), (R6), and (R7) represent the respondents. Direct quotations from the respondents will be included in the description when relevant.

Semi-structured interviews were applied to capture the experience from the participating experts. When applying semi-structured interviews it is important that the conversation is directed by the respondent rather than by the set of questions. Therefore, open questions were prepared to add flexibility and structure to the interview. The questions served in this way as a checklist which purpose was to ensure that

all relevant topics were covered. During the interview the main questions were supported by follow-up questions and probes to increase details and provide clarification (Rubin and Rubin 1995). Because of the open structure where the respondent's response cannot be predicted in advance, the follow-up questions and probes could not be prepared on beforehand (Wengraf 2004).

The interviews have afterwards been transcribed, and translated from Danish (recording language) into English and in that process rectified contextual as well as grammatical, thereafter it has been sent back to the respondents for approval. The respondents were given a 14 days response time for validating quotations.

2.4 Validity and trustworthiness

Validity of the conducted research is of crucial importance. Validity or research quality is dependent on the trustworthiness of the study. Guba (1981) identifies four aspects of trustworthiness: 1) truth value, 2) applicability, 3) consistency, and 4) neutrality. 1) Truth value is concerning the confidence in the "truth" of the findings (Lincoln and Guba 1985). 2) Applicability refers to the extend the results can be transferred to other settings or groups (Krefting 1991). 3) Consistency is referring to the consistency in the results and thus referring to the possibility of replicating the research (Krefting 1991). 4) Neutrality is focusing on ensuring that the results solely are caused by the object studied, and thus eliminating external biases (Krefting 1991).

The strategy to secure trustworthiness depends on whether the research study is qualitative or quantitative. The different strategies are summarized in Table 2, while an in-depth description can be found in Krefting (1991).

Table 2: Strategies to fulfill trustworthiness criterion (Krefting 1991).

Criterion	Qualitative Approach	Quantitative Approach
Truth value	Credibility	Internal validity
Applicability	Transformability	External validity
Consistency	Dependability	Reliability
Neutrality	Confirmability	Objectivity

A number of different techniques exist to ensure the fulfillment of the four criteria, but it is important to notice that not all techniques are appropriate to every study (Krefting 1991). The selected techniques to the four main research elements included in this research study are presented in Table 3. A description of possible techniques for qualitative as well as quantitative studies can be found in (Krefting 1991).

Table 3: Applied techniques to ensuring trustworthiness of the research results.

Literature review	
Truth value	-Peer examination, see Lincoln and Guba (1985). Discussing the research processes and findings with supervisor.
Applicability	-Not relevant.
Consistency	-Dense description of the research methods, allowing other researchers to follow the decision trail and to audit the results, see Guba (1981). -Peer-examination of methods, method is reviewed and discussed with the supervisor.

Neutrality	-Not relevant.
Questionnaire	
Internal validity	-Ensured that the same person did only participate once. - Applying an electronic survey to expand the sample.
External validity	-Demographic considerations, the selected participants did cover all different organizational levels and thereby contribute with different experience to production control.
Reliability	-Triangulation of methods, by comparing the findings with findings from the case study. -Peer-examination of methods, method is reviewed and discussed with the supervisor. -Dense description of the research methods, allowing other researchers to follow the decision trail and to audit the results, see Guba (1981).
Objectivity	-Following a questioning technique to avoid affecting the responses.
Case studies: the qualitative part	
Credibility	- Triangulation of data sources, by following 4 different construction cases. - Prolonged engagement, making observations over a period of time to identify recurrent patterns c.f. (Lincoln and Guba 1985). -Peer examination, see Lincoln and Guba (1985). Discussing the research processes and findings with supervisor.
Transformability	-Demographic considerations, where construction sites involving different companies were followed to capture differences in application, see Krefting (1991).
Dependability	-Dense description of the research methods, allowing other researchers to follow the decision trail and to audit the results, see Guba (1981). -Peer-examination of methods, see Lincoln and Guba (1985). Method is reviewed by the supervisor.
Confirmability	-Reflexivity, considering researches influence on the observed and seek towards neutrality, see Guba (1981).
Case studies: the quantitative part	
Internal validity	-Dependent variables are isolated. -Prolonged measurement to ensure a large data sample to minimize the risk of randomization.
External validity	-Following more cases to expand the data sample and to make generalizations possible, c.f. Payton (1979). Including different companies and different categories of construction projects (housing and refurbishment).
Reliability	-Hypothesis testing of results to document reliability. -Peer-examination of methods, method is reviewed and discussed with the supervisor. -Dense description of the research methods, allowing other researchers to follow the decision trail and to audit the results, see Guba (1981).
Objectivity	-Data collected mainly form archives. By observing the registration it was insured that the site-manger did rigor follow the defined methods for registration.
First interview session	
Credibility	- Triangulation of data sources, by interviewing 3 different site-managers. - Prolonged engagement, allowing the respondents to be familiar with the researcher before conducting the interview which according to Kielhofner (1982) will increase the likelihood of discovering hidden facts. - Peer examination, see Lincoln and Guba (1985). Discussing the research processes and findings with supervisor.
Transformability	-Demographic considerations, where multiple site-mangers form different companies were interviewed, see Krefting (1991).
Dependability	-Dense description of the research methods, allowing other researchers to follow the decision trail and to audit the results, see Guba (1981). -Peer-examination of methods, see Lincoln and Guba (1985). Method is reviewed by the supervisor.
Confirmability	-Reflexivity, considering researches influence on the observed and seek towards neutrality, see Guba (1981).
Second interview session	
Credibility	- Triangulation of data sources, by interviewing 7 different experts. - Member checking, by enabling participants to read, make comments and approve own statements, see Lincoln and Guba (1985). - Peer examination, see Lincoln and Guba (1985). Discussing the research processes and findings with supervisor.
Transformability	-Demographic considerations, participants were selected to cover different areas and experiences with production control to ensure that all gaps in the profile was filled, see Krefting (1991).
Dependability	-Dense description of the research methods, allowing other researchers to follow the decision trail and to audit the results, see Guba (1981). -Peer-examination of methods, see Lincoln and Guba (1985). Method is reviewed by the supervisor.
Confirmability	-Reflexivity, considering researches influence on the observed and seek towards neutrality, see Guba (1981).

The PhD project as a whole

Truth value	<ul style="list-style-type: none">-Triangulation of methods, by applying 4 different research approaches, see Knafelz and Breitmayer (1989).-Establishing authority of researcher, see Miles and Huberman (1984). As an author I have through the literature acquired theoretical knowledge to the subject of interest. Moreover, through courses PhD seminars I have become familiar with both quantitative and qualitative research.-Negative case analysis, by shaping the research study as a result of collected data and by reconsideration and even rewriting the research hypothesis, see Mills <i>et al.</i> (2010).- Peer examination, see Lincoln and Guba (1985). Discussing the research processes and findings with supervisor.
Applicability	<ul style="list-style-type: none">-Ensured directly during the research processes.
Consistency	<ul style="list-style-type: none">-Dense description of the research methods, the research structure, and the research paradigm.-Peer-examination of methods, research structure, and research paradigm are reviewed by the supervisor.
Neutrality	<ul style="list-style-type: none">-Reflexivity, considering researches influence on the observed and seek towards neutrality, see Guba (1981).

3. Exploring for excellence within Last Planner System

In the attempt to improve both the effectiveness and efficiency of LPS, the production control system has been examined. Throughout the conducted study several points of criticisms to the existing production control tool have been stated. Thus, the study is forming the research- and theoretical background to the revised production control system. To support the new system, production control experts have evaluated the improved system, and their opinions and comments have been incorporated into the system design.

3.1 A new framework for Production Control in Complex and Constrained Construction Projects (PC⁴P)

The framework of the PC⁴P system is shown in Figure 1. The framework is overall consisting of four key schedules (marked with gray): The Master Schedule, the Phase Schedule, the Look-ahead Schedule, and the Commitment Plan. Moreover, the input to create the schedules are sketched (marked with green) together with support activities (marked with blue), which often is creating a link between schedules. Finally the external environment (marked with red) and its impact on the production control system is sketched. In the remaining pages in this chapter the developed framework for production control is explained in detail.

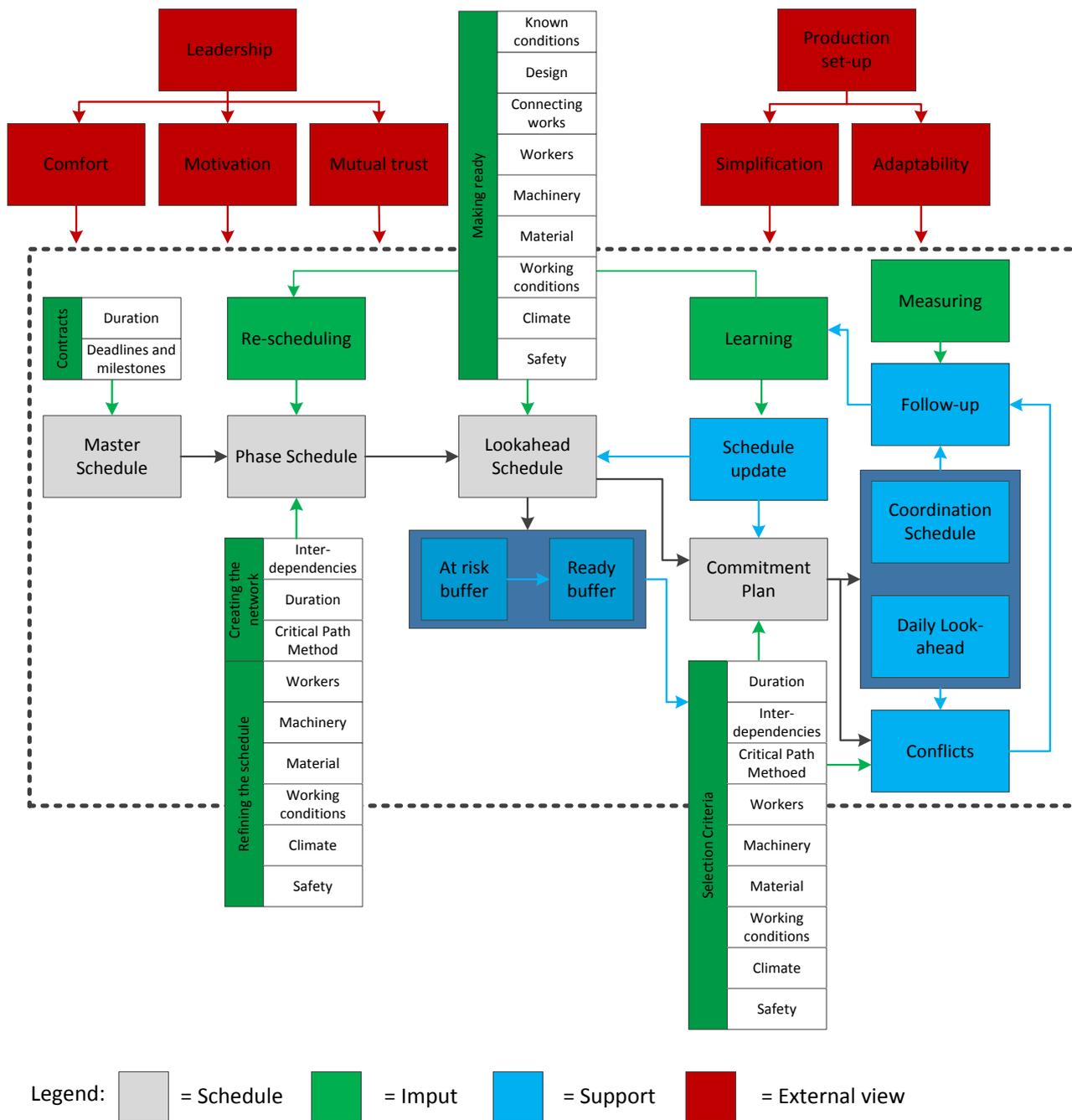


Figure 1: The PC⁴P framework.

3.2 Application and implementation of the PC⁴P framework

As the PC⁴P framework reveals, production control in on-site construction is complex. Numerous of parameters have an influence on the process and the performance on-site. (R1) elaborates: "Actuality, the framework does illustrate why production control in construction is so difficult, namely because of all the considerations you need to incorporate in the schedule".

A production control system consists of a set of elements, where the interplay between the applied elements are making the system complete. The production control system is a thought through system

where every applied element serves its unique purpose, it is therefore critical if central parts of the PC⁴P framework are omitted as often being the case with current practice of the scheduling tool LPS (Lindhard and Wandahl 2012a). If changes or adjustments are made to the PC⁴P framework it is essential that the production control system is fully understood (Lindhard and Wandahl 2012a). Minimal knowledge combined with inconsiderate changes is according to Lindhard and Wandahl (2012a) considered being one of the main barriers which have to be overcome to achieve a more reliable schedule. (R2) points out that *“it is people not systems who build. The system is not stronger than the people who uses it; therefore, it is crucial important that everybody understands the system and applies it correctly”*. To avoid a complex and inflexible production control system (R1) expresses the importance of still *“not to follow the production control system blindly but implement the intentions within the system; here sense of propriety is crucially important”*. When applying the PC⁴P framework, the degree of formalization and the level of depth and considerations put into the schedules should be fit to the actual construction project, but still with respect for the system which should be applied as a whole. (R7) elaborates: *“The framework is very theoretical, a lot of the input will take place implicit, thus it is important that you adjust the need for documentation and formalization in the production control system to fit current needs”*. It is a site-management task to ensure that the production control system is correctly applied; thus, the site-manager shall introduce and support the subcontractors’ application of the PC⁴P framework (Lindhard and Wandahl 2012f). Moreover, the site-manager is responsible for successfully organizing of scheduling meetings. Meetings should be limited to avoid long sessions of inactivity which, according to Lindhard and Wandahl (2013a), results in decreased concentrations levels, which induce low scheduling quality and slow progress. According to (R3) *“it is important to consider, task relevance and detail level for discussions in plenum”*. To minimize inactivity it was, during the interview, suggested (R1) *“to start the meeting by focusing on the subcontractors with only little work on-site, and when all topics relevant to the subcontractor are discussed, they should be allowed to leave the meeting”*. (R2) agrees and states: *“It is very important to organize the meeting like this, and it is perfectly normal”*.

The next step is implementation of the PC⁴P framework, to this (R5) states *“I think these are some good additional contemplations in relation to LPS. Now we just need them implemented”*. Correct implementation and application is important for both efficiency and effectiveness of a production control system. Throughout a literature survey Vishal *et al.* (2010) find 12 different challenges which have affected the implementation of LPS. According to Lindhard and Wandahl (2012f), the consequence of these challenges has been untapped reliability and reduced productivity. To overcome the 12 implementation challenges, Lindhard and Wandahl (2012f) identify two factors of particular importance: willingness to succeed and knowledge. *“Knowledge is important to secure a correct, implemented and applied system while willingness or stubbornness is important to maintain and anchor changes deep into the organizational behavior.”* (Lindhard and Wandahl 2012f)

3.3 The surrounding world

The PC⁴P framework is based on an open system-theory mindset and consists of connections, components, and input. The mindset of the open system-theory regards the environment as dynamic and interacting with and influencing on the system. In this theoretical setting, the surrounding world is creating the outer context wherein the production control system functions (Lindhard and Wandahl 2013a) and is thereby influencing both behavior and process (Hartley 2004), and thus having a huge impact on the performance

of the production control system. Thus, by changing the surrounding world the system is changed, cf. Leavitt's Diamond. Because of the importance and impact, the surrounding world is added to the PC⁴P framework, this is done to increase awareness to the interrelationship. Three parameters have been identified as crucial parameters, which affect behavior and thereby application of the production control system: Comfort, motivation, and mutual trust, while two parameters have been identified as crucial parameters, which affect the process in the production control system: Simplification and adaptability.

3.3.1 *Comfort, motivation, and mutual trust*

According to the Lean-philosophy the capacity of the production system is equal to the sum of work and waste (Ohno 1988). Transformations are driven by the workforce present on-site, and Lindhard and Wandahl (2012c) find that the skill and motivation have a huge impact on the output both regarding quality and quantity. Improving skills adds knowledge and expands the capacity within the production system while an improved motivation secures exploitation of capabilities which already did exist inside the production system (Lindhard and Wandahl 2012c). Lindhard and Wandahl (2012c) find that the theorem could be even more generalized and concludes that *"Waste is not to fully utilize of the capabilities and possibilities in the production system."* The theorem expands Lean's existing 7 types of waste; see Suzaki (1987) or Ohno (1988), and defines the 8th source to waste.

Today Lean and LPS have a perfunctory approach to the production system which causes the human aspect to be overlooked (Lindhard and Wandahl 2013a; 2012c). By establishing comfort and mutual trust between the individual craftsman, motivation and collaboration will increase. Increased motivation induces increased accountability and productivity (Olomolaiye 1988; Singh 1996). Improved accountability produces dedication and raises the likelihood of observing the scheduled commitments which lead to increased schedule robustness (Lindhard and Wandahl 2013d; 2012c). Lindhard and Wandahl (2012c) state that Lean and LPS can be improved by focusing not only on transformations but also on the ethical values and leadership which guide and support the transformation process and on-site behavior to foster comfort, motivation and mutual trust between all project participants. (R6) states: *"Leadership is to me important; how you act and talk to people certainly has an effect on motivation and is moreover having influence on the quality of the work performed"*. This is supported by (R5) who elaborates: *"As a leader, you have a huge part of the responsibility regarding the job satisfaction and motivation. By being the good example you help creating mutual trust and respect between the project participants."* (R1) points out that *"leadership is important to make the production control system function; this includes how you bring the production control system into play, and how you facilitate your meetings"*.

3.3.2 *Simplification and adaptability*

A construction process is dominated by changes which make the process complex and difficult to schedule. To increase customer value Lindhard and Wandahl (2012g) suggest that the owner should complete a *"lifecycle"* plan of expected usage within the buildings lifetime. Moreover, future usage should be incorporated into the building's design. According to Lindhard and Wandahl (2013b) the *"lifecycle"* plan will force the owner to consider future usage of the building which will make the design thoroughly thought out limiting the amount of design changes. Thus, a *"lifecycle"* plan will reduce the design changes during the construction process and thereby simplify production control. (R7) adds: *"Lifecycle considerations are*

gaining a broader acceptance, but still some owners focus on having the building completed as fast and as cheap as possible”

The complexity of the construction process is very much affected by decisions taken outside the boundaries of the production control system. By simplifying the production, waste can, in accordance to the Lean philosophy, be reduced (Lindhard and Wandahl 2012b). The degree of prefabrication, preassembly and modularization are all affecting the site setup by affecting the number of tasks and trades on-site, which according to Lindhard and Wandahl (2012b) simplifies the process. Another advantage to prefabrication, preassembly and modularization is according to (R2) that *“the output quality is improved”*. Reducing tasks and trades on-site reduce interdependencies and increase process transparency and thus simplify the production control (Lindhard and Wandahl 2012b). If the work tasks on-site are simplified to only include the assembly process, the task complexity is reduced decreasing the needs of specialized craftsmen and the need of different trades to be present at site. The negative effect of reduced tasks on-site is decreased adaptability inside the process. (R5) reports that *“the problem arises when you need to replace a prefabricated element, then you are dependent on your supplier’s delivery time”*. Reduced adaptability in the process has been reported by (R4) who states: *“We have a large delay in the production; because of scheduled deliveries of prefabricated cassettes we have been forced to store the cassettes elsewhere”*. Contrary, does *“Less specialization equals more flexibility and adaptability in the assembly process.”* (Lindhard and Wandahl 2012b). Of course one could argue that even though the site management is simplified, the complexity is just moved outside the boundary of the construction site. But off-site the production facilities can be improved to a factory-like state which makes it possible to streamline the production and to increase productivity. Moreover, since more complex products are delivered to site, the number of subcontractors is reduced which simplifies contract management. Off-site production will make it possible to reduce the lead time but as a downside the result is a tighter schedule. Thus, off-site production is more dependent of on-time delivery.

Adaptability is, according to Lindhard and Wandahl (2012b), defined as the ability to convert the production from one task to another. Thus, increased adaptability is enhancing the ability to respond to unforeseen events and is thereby reducing waste in the adjustment process (Lindhard and Wandahl 2012b). Adaptability can be achieved by improving task or process adaptability which in general is achieved by increasing flexibility. A factor affecting tasks adaptability could for instance be buffer considerations while a factor affecting process adaptability for instance could be workforce flexibility (Lindhard and Wandahl 2012b). According to (R5) *“On-site, it newer turns out as planned; therefore, flexibility and especially workforce flexibility is crucially important. Sometimes you will need a crew to change work task, sometimes to work overtime or to work in the weekend”*.

3.4 Master Schedule

The Master Schedule serves as guidance for the more detailed schedule. Therefore, at the Master Scheduling level the focus should be on creating overview to the upcoming construction process. When creating the overall schedule, the input is estimated durations and the under the contract set deadlines and milestones. It is important that the time boundaries set by the contract are realistic; both a too tight and too slack time frame is undesirable (Lindhard and Wandahl 2012d). A too tight time frame will be inflexible and thus unable to absorb variation in production while a too slack time frame entails unexploited or wasted time deteriorated by the industry tendency to work best under pressure (Lindhard and Wandahl

2012d). (R5) agrees and states *“preferably, the schedule should be realistic but tight so you still are being put a little under pressure”*. Lindhard and Wandahl (2012d) recommend that the deadline is realistic but flexible. The flexibility aspect is introduced to encourage increased collaboration and negotiation between contractor and client to create win/win situations and to move the construction industry away from contract bonded projects and bring both productivity and value creation up (Lindhard and Wandahl 2012d). R(4) points out that even though *“win/win situations definitely will create motivation. The motivation still needs to be passed on down to the craftsmen on-site to have an optimal impact.”*

3.5 Phase Schedule

At the Phase Schedule level the primary task is to create the overall network of activities (Lindhard and Wandahl 2013b); the network is structured in a network chart. The basic parameters to define this network and draw the overall connections include: relevant activities to identify durations, handoffs to identify interrelationships, and the Critical Path Method (CPM) to identify the critical path and possible slack within the construction process (Lindhard and Wandahl 2013b). To minimize the risk of delay slack should, if possible, be incorporated on the critical path to absorb small variations (Lindhard and Wandahl 2012b; 2012d). Incorporating slack on the critical path is contrary to the CPM concept, but opposite CPM, PC⁴P does not seek to finish as fast as possible, but instead exploit the given time limits to increase the schedule robustness. According to Lindhard and Wandahl (2013a; 2013b), the network can be refined by incorporating the preconditions to sound work tasks into the selection and sequencing process to identify and consider all critical elements in the existing schedule. Moreover, refining the network is an attempt to improve the utilization of the capabilities in the production system cf. (Lindhard and Wandahl 2012c). According to (R4) *“there are always elements in the schedules which are not thought through; basically it is all about identifying these critical elements as early in the process as possible. Today you need to include much more considerations into the schedules”*. Moreover (R3) elaborates *“including more parameters in the selection of activities is a good idea and can help to identify critical elements”*.

The preconditions to sound work tasks are by Lindhard and Wandahl (2012e) divided into nine preconditions: 1) Known conditions, 2) construction design and management, 3) components and materials, 4) workforce, 5) equipment and machinery, 6) working conditions, including space, 7) connecting works, 8) climate, and 9) safety. Through an in-depth analysis it was found that only six of the preconditions are of importance in the refining process (Lindhard and Wandahl 2013b). The remaining three preconditions are only important in the making ready process to ensure that the activity can start and are not important during execution and are therefore not having an impact on the sequence (Lindhard and Wandahl 2013b). The relevant preconditions include: machinery, material, workers which comprise the needed resources and working conditions, climate, and safety which affect the pace of the work (Lindhard and Wandahl 2013b). According to (R7) *“all six preconditions are of relevance to the schedule”*. And (R6) states: *“You could easily have included the six flows to improve and refine the network, but in this construction case we have mostly been interested in time”*. In the following the underlying planning procedures, to include the six preconditions in the overall schedule, are presented:

3.5.1 Workers

The manning level on-site has an impact on labor performance (Hanna *et al.* 2005). Lindhard and Wandahl (2013b) recommend to avoid fluctuation in manning, especially within the trades, because it streamlines

and simplifies buffering of activities where one week's buffer-window equals one week of ready work (Lindhard and Wandahl 2013a). By keeping a steady manning within the trades extremes in the manning are avoided which eliminates the risk of overmanning; which decreases productivity (Hanna *et al.* 2005). To calculate the manning throughout the construction project the needed workforce to each activity first has to be estimated. Afterwards, the manning is summarized, for instance from a Gant-diagram or a cyclogram, into a stacked column chart. In this process activities can be rearranged to attain a steady manning, and the initial schedule is updated. The process is illustrated at Figure 2.

Changing orders due to changes in schedules and plans decreases labor efficiency (Hanna *et al.* 1999; Moselhi *et al.* 1991), and should be minimized. When orders on-site are changing the manning should ideally remain unaffected. Heighten the manning accelerates the work output but reduces labor productivity (Hanna *et al.* 2005), while lowering the manning decreases the work output and creates delay (Lindhard and Wandahl 2013b). Finally, to improve output quantity and quality, comfort of the individual craftsman should be secured (Lindhard and Wandahl 2013c; 2012c).



Figure 2: Example; adjusting the manning. Entrepreneur A (marked with green) is secured an even manning by exploding the slack and thereby moving activities.

3.5.2 Machinery

Required equipment and machinery is important mainly from an economical perspective. By compiling activities in relation to needed machinery, the utilization rates will increase and necessary presence will be restricted, reducing rental costs (Lindhard and Wandahl 2013b). The utilization rate can easily be calculated, in a Gant-diagram or cyclogram, by linking the needed machinery to each work activity. In this process activities can be rearranging to increase utilization or to avoid conflicts such as double usage which easily is

spotted. Afterwards, the initial network chart is updated in relation to the relevant changes and restrictions identified in the utilization-diagram. Increased utilization rates of shared equipment increase the interdependencies and necessity of well-functioning machinery. A small gap between handoffs can be incorporated to absorb small variations in duration and thereby avoid an infectious delay (Lindhard and Wandahl 2013b; 2012b). Finally, an emergency plan can be created to minimize the effect of critical breakdowns (Lindhard and Wandahl 2013b). The process of incorporating machinery issues is illustrated in Figure 3.

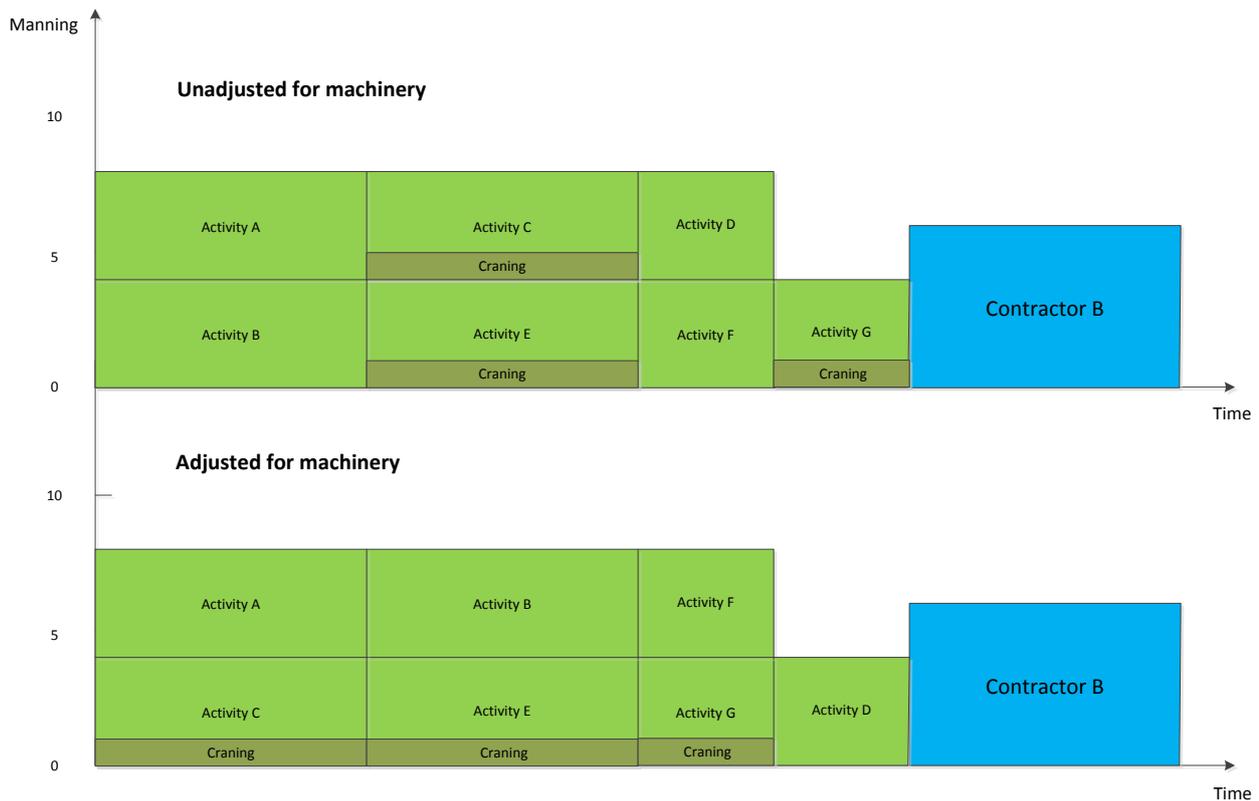


Figure 3: Example; adjusting usage of machinery. Entrepreneur A (marked with green) is secured an even flow in equipment and machinery by moving activities within the limits of slack and interdependencies.

3.5.3 Material

In construction every work activity is unique and requires its own unique materials and components. The result is thousands of different materials which all, in time, has to be delivered to the correct work activity. Material delivered just-in-time has an increased risk of non-presence at activity start, while material delivered too early has to be stored and re-handled which increases cost (Lindhard and Wandahl 2013b). To increase the flexibility of material deliveries, materials should not be pushed to the site by fixed material deliveries but should instead be pulled to site, thus delivered when needed. Storing of materials has to be done carefully to reduce the likelihood of dwindling or damaged materials (Lindhard and Wandahl 2013b). To create overview, the material needed for each work activity is defined and stored in a material log. Afterwards the material flow is printed from a cyclogram, or in a BIM-model. Two initiatives to ensure consistency of supply and to simplify execution are suggested. 1) Hiring specialist to manage the procurement of materials. 2) Delivering materials in units containing all materials needed in a predefined

room. The capacity of the access roads is estimated, to identify possible bottlenecks and to identify and consider relevant logistic issues. If capacity problems or bottlenecks are identified the material flow is adjusted either by controlling material deliveries or in extreme cases by rearranging the order of the activities. Examples to problematic logistical conditions could be restricted and time-bound access or limited access roads and “material-carriers”, like in offshore construction. According to (R4) “restricted access is very likely to occur during a construction process”. The process of adjusting the Phase Schedule in relation to material issues is illustrated in Figure 4.

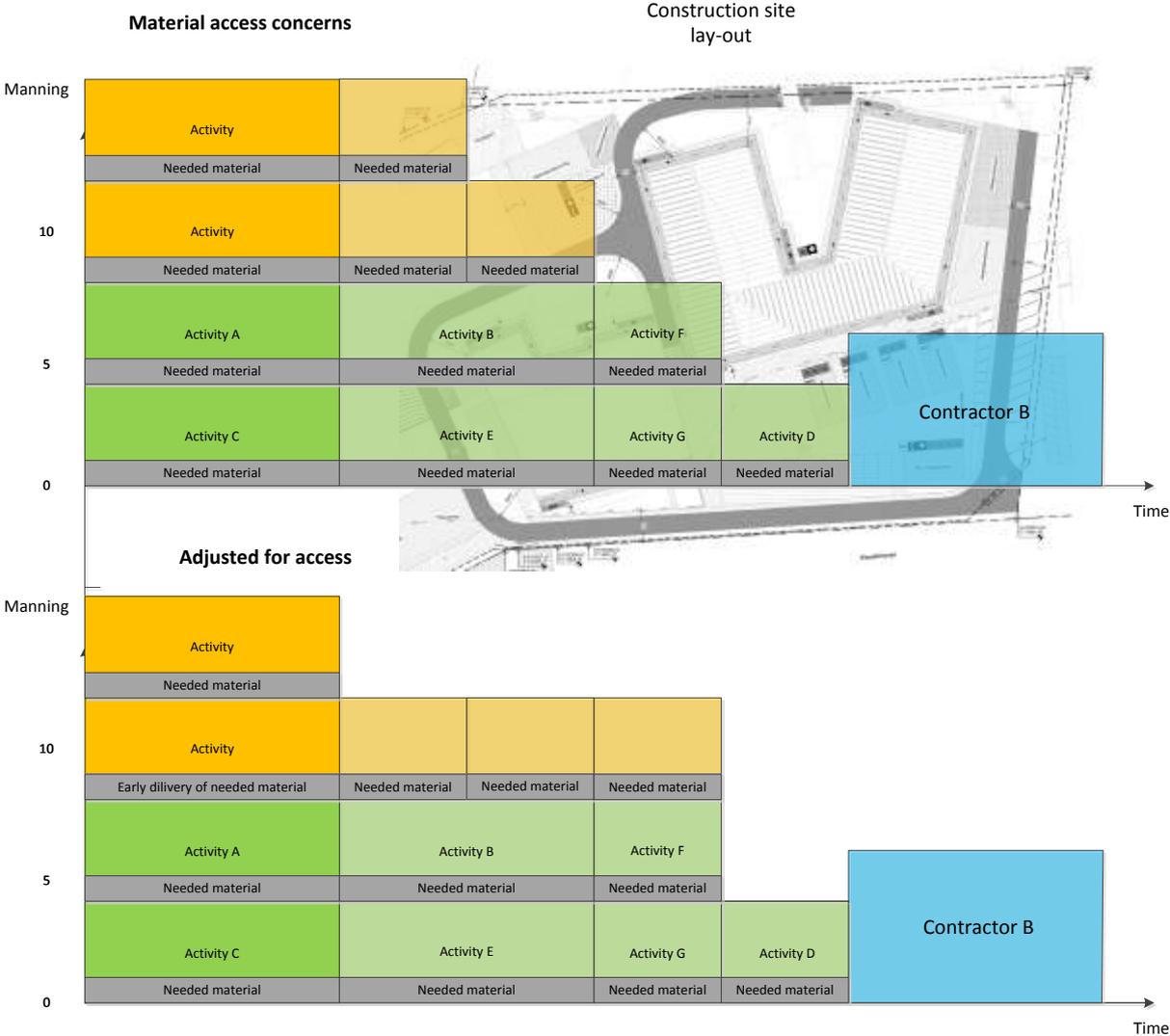


Figure 4: Example; adjusting for material access. Material demands are compared to the lay-out of the construction site to spot critical bottlenecks. Bottlenecks are avoided by moving either delivery or the whole activity.

3.5.4 Working conditions

Lindhard and Wandahl (2013b) rename the space category to working conditions, because it includes all elements affecting the working conditions. According to Lindhard and Wandahl (2013b) working conditions include: “working comfort, for instance temperature, lighting, noise, working postures, working procedures, working base etc. Moreover, working conditions do as mentioned include space issues, which include access to work place, mutual interruptions and delays caused by shared work areas, etc.” Working comfort is much

related to traditional working environment issues, which is a part of safety. But where working environment is focusing on the health and safety of the workforce working comfort is focusing on output and quality. Therefore, to increasing output and quality, working comfort includes initiatives which go beyond the safety guidelines. Ideologically space is handled through the PostIt session where interdependence is considered (R7) explains: *“If the flow is adjusted correctly through the PostIt-session, there should only by one trade at a working area at a time”*. But often you need a more detailed knowledge on space usage, because (R7) *“trades, either to win time or because it fits the process more naturally, start to work in the same working areas simultaneously.”* To increase knowledge, and to handle and optimize space issues, working areas and space requirements to every activity are defined (Lindhard and Wandahl 2013b). Afterwards, usage is linked to the schedule to ensure that space is available; this can be achieved by applying Location Based Scheduling, for instance a cyclogram or by using BIM. (R4) *“If you apply a cyclogram and keep it at a simple level with few subcontractors and few lines it can be really useful, but be careful because you can easily loose the overview.”* Furthermore (R1) notes that a more visual scheduling approach is an advantage and states: *“In the future, scheduling will be more visual because the craftsmen are very visual”*. Working comfort is secured by identifying and controlling all relevant parameters to improve the working conditions. A log book is used to include all initiatives wherein good working comfort is also defined. Finally, the initial schedule is updated to contain the effects of the working conditions. The process is illustrated at Figure 5.

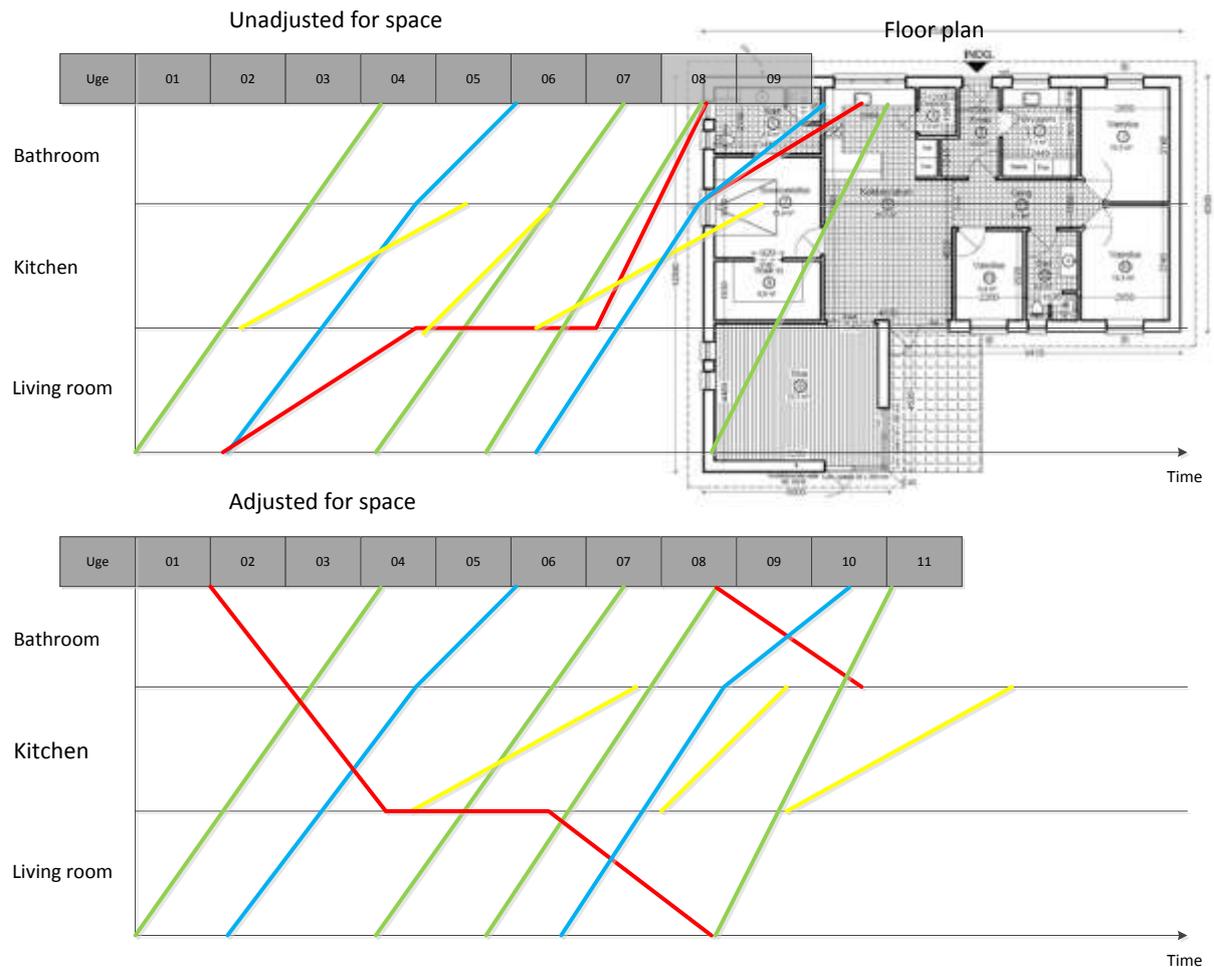


Figure 5: Example; adjusting for space usage. Applying a cyclogram and compare it to the floor plan to identify insufficient space and adjusting sub-sequences. The colors in the cyclogram represent the subcontractors on-site.

3.5.5 Climate

Every construction project is surrounded by its unique, complex, and changing external climate. The external climate does by a number of parameters such as temperature, wind, moisture, rain, snow, waves, and visibility (Lindhard and Wandahl 2012b) affect the work conducted at site. The climate itself is unchangeable but the negative effect of the climate can be handled and reduced (Lindhard and Wandahl 2013b). Even though the climate-parameters follow the season, the climate impact, especially at long term, is often impossible to forecast. Quick changes in the climate combined with long installation time makes it necessary to implement some precautions at a long term basis, before the possible effect is known. Other precautions can be implemented at short term, when necessary. Therefore, as a part of the long term scheduling Lindhard and Wandahl (2013b) state that critical parameters need to be identified and possible precautions have to be considered. (R5) elaborates *“If the schedules reveals that joint-work (a summer activity), is going to take place during the winter, you have to consider how to solve the related problems”*. The economical perspective is an important parameter when considering precautions, but since long term forecasts are unreliable the total economical perspective is impossible to calculate and thus the decision should be based on risk assessments (Lindhard and Wandahl 2013b). Incorporation of climate differs on today’s construction site (R2) states: *“We consider climate parameters and show consideration for summer*

and winter work task.” But opposite, (R7): “climate is not considered when scheduling. Instead problems are considered when emerging. Everything can be solved it is just the matter of at what cost”. In this context (R5) points out that “bad weather should actually be contained in the schedule, therefore the construction period should actually be prolonged”. Relevant precautions to consider could for instance be covering, heating, snow removal, water protection etc. Selected precautions are kept in a climate log and implemented when necessary. In identified critical scenarios the climate log is expanded by a set of thought through actions to handle the crisis. The schedule is updated, including all relevant effects from the climate precautions. Adjusting the Phase Schedule in relation to climate issues is illustrated in Figure 6.

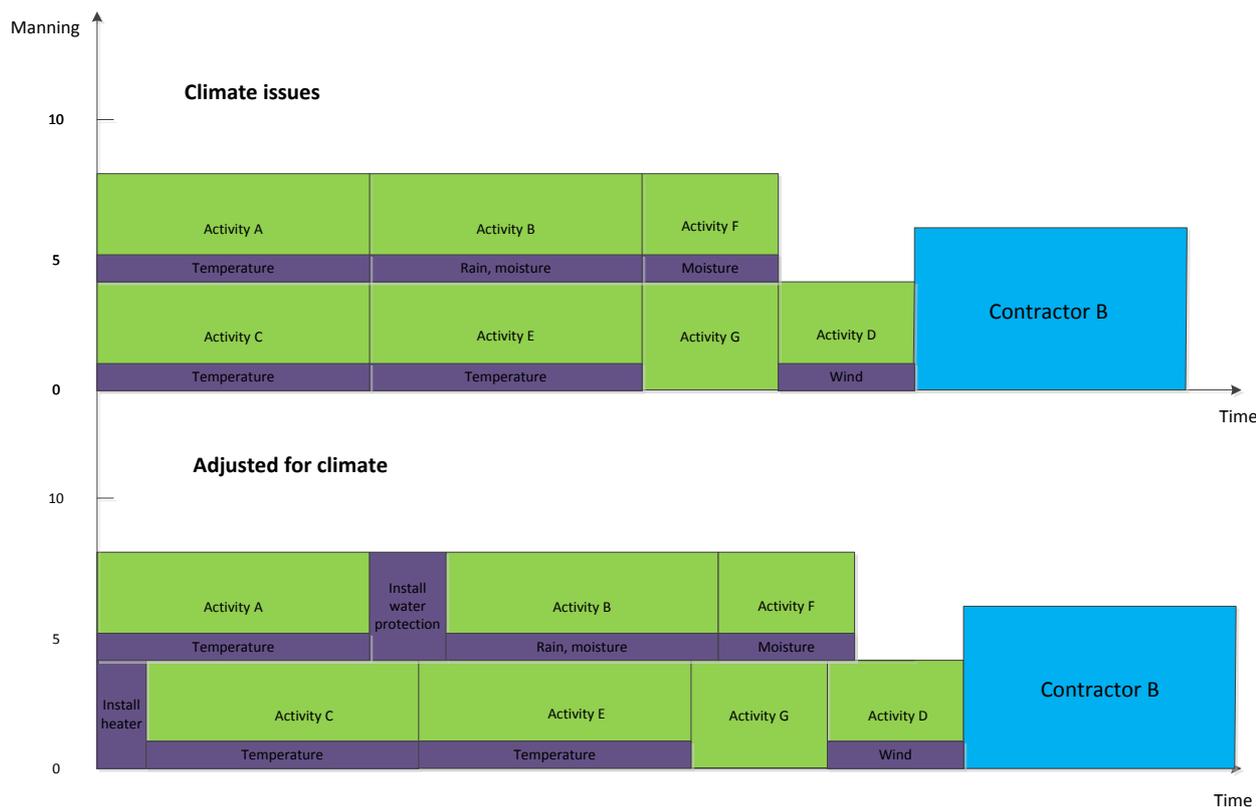


Figure 6: Example; incorporating climate conditions. Entrepreneur A (marked with green) is handling climate conditions by noting and incorporating relevant climate precautions into the schedule. The notes serve as a reminder to climate concerns.

3.5.6 Safety

Before an activity is completed, it is crucial to ensure the safety of the work crews completing the task. Therefore, at activity level the necessary safety precautions have to be identified and implementation planned (Lindhard and Wandahl 2013b). According to (R2) “safety is very relevant and is affecting the sequencing. If not considered already at this stage, it is a risk that safety issues might stop the production”. Moreover (R5) elaborates “especially safety should be considered more in the schedules”. Relevant precautions could be safety distance, fall protection, covering of unsafe areas, access roads, etc. Besides direct safety fulfillments cf. the national “Health and Safety at Work Act”, other preventive precautions could include: safety inspections, safety trainings, hazards planning, alcohol screening etc. (Howell *et al.* 2002). Moreover, all on-site shall have safety awareness in an attempt to hinder problems in developing. All safety precautions are summed in a safety log list. The initial schedule is updated if the safety probations

are adding extra tasks or requiring changes in existing work tasks. Besides increased safety, the safety log helps in detecting problems on beforehand, which releases time wherein the optimal solution to the problem can be found. The process of incorporating safety issues is illustrated in Figure 3.

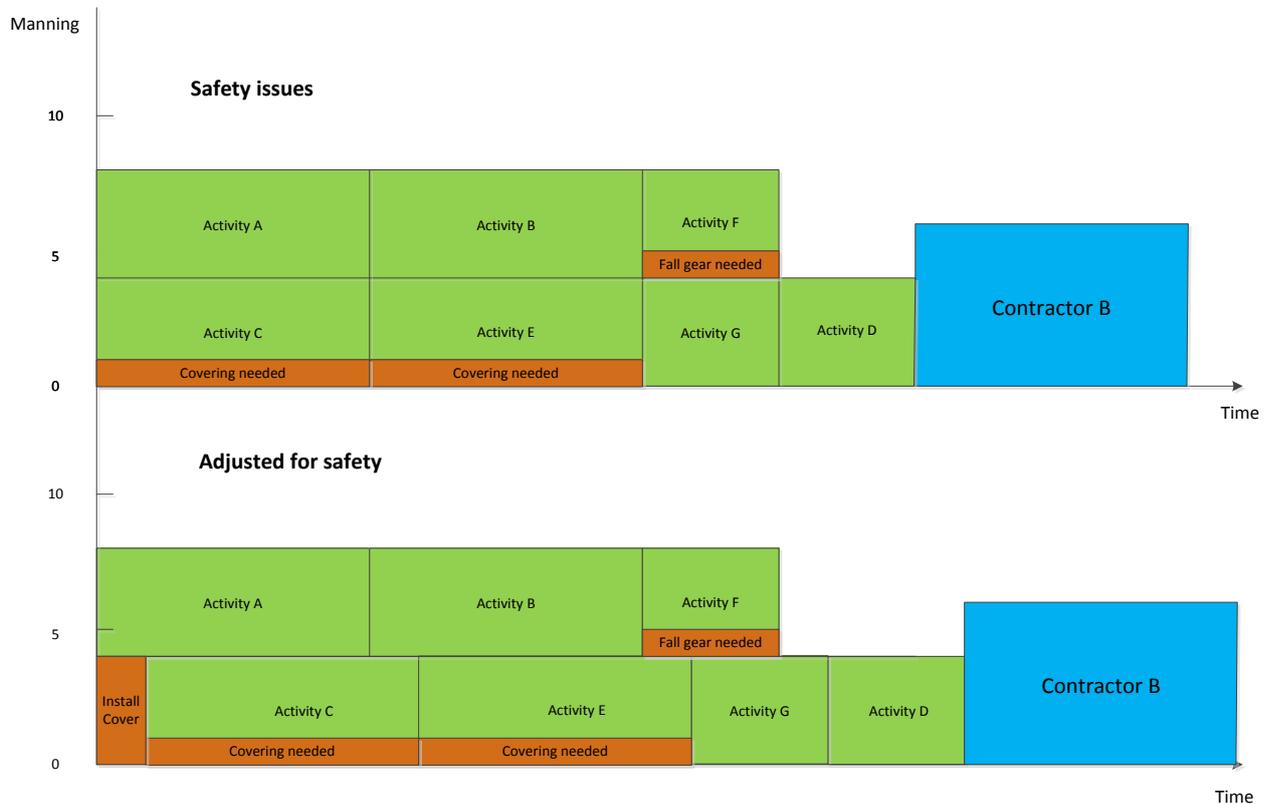


Figure 7: Example; incorporating safety. Entrepreneur A (marked with green) is securing a safe working environment by noting and incorporating relevant safety precautions into the schedule. The notes serve as a reminder to safety concerns.

3.5.7 Re-scheduling

In the search for continuous improvement the Phase Schedule has, at selected repetitive tasks, to be re-done. By returning to the scheduling phase process, positive and negative experience can be discussed, and overlooked sub-activities and problems can be incorporated into the schedule. Thus, does the re-scheduling of the Phase Schedule create an opportunity to learn during construction. (R6) states: *“It makes sense to rethink the process. You could easily sit down and talk with your foremen and together uncover the improvement which can be incorporated when the process is repeated”*. (R1) elaborates: *“I have tried it – the result was that we changed the process”*. (R5) agrees and points out that *“often the design is changed during construction, which changes the interdependencies”*.

Moreover it was during the interview suggested that the re-scheduling could be combined with traditional waste reduction. (R4) *“It will really create value if you mapped the process to identify waste, to see if anything can be removed. The potential is huge and it is a fundamental part of the Lean principals. Moreover, I think that it is not only money and time which is at stake it is also motivation and ownership”*.

(R7) elaborates, *“in the construction industry we are alarmingly poor at uncovering waste. We try to handle the effects and not to remove the causes, instead we continue to the next issue”*

3.5.8 *Summing up*

In most situations there is no optimal schedule because the demands of the different parameters are conflicting with each other. The final schedule is therefore based on the site-managers individual prioritization between the different parameters. Thus, it is the site-manager’s responsibility to ensure that the best possible schedule is achieved. It is important to state that incorporation of the six flows into the schedule is an analysis which takes place after the traditional PostIt session. This is supported by (R1): *“Including the six flows seems reasonable as long as it does not take place at the traditional workshop”*. (R3) is concerned about maintaining overview *“to me the six flows are a danger signal; you have to be careful not to lose overview of the process”*. (R5) is concerned about the process to be troublesome and time-consuming but is after consideration concluding: *“it is a question of changing position. By making a more worked out Phase Schedule, you will probably save time in the long run”*. (R4) finds the six flows relevant and elaborates *“Over time, I have been engaged at several construction projects, and I have noticed that in the construction industry we skim over the preliminaries and do not carefully enough consider the process. Thus, a lot of interdependencies are revealed too late, this is creating chaos.”* Most often the unrevealed interdependencies are not discovered until the completion of the activities is started.

Variations occur, but both positive and negative variation is undesirable (Lindhard and Wandahl 2012a). To ensure that the predefined conditions which compose the basis of the schedule are not changing: durations, interdependencies, flows, slack, and critical path need to be continuously monitored (Lindhard and Wandahl 2013a). Monitoring the parameters can help detecting and avoiding possible conflicts to evolve (Lindhard and Wandahl 2013a). If the basis of the schedule is changed the schedule needs to be rethought and adjusted.

The stage of the construction process is based on the completion of construction activities. Everything is organized with respect to time usage which often is referred to as the most important parameter (Lindhard and Wandahl 2012d). Today positive variation in duration often ends up as unexploded gaps between activities while negative variation result in delays (Howell and Ballard 1994; Lindhard and Wandahl 2013c). The wasted gaps are an effect of construction complexity where multiple trades are completing highly interdependent activities. According to Lindhard and Wandahl (2013c) *“Interdependencies between the multiple trades on-site make it difficult to adjust the sequence because the next trade is often occupied elsewhere, not-aware of the gap, or simply not ready to start the conduction of the following activity.”* Moreover Lindhard and Wandahl (2013c) state that *“The positive variation is exploited if the utilization of the capabilities in the production system is kept high.”*

To hinder delay positive variation needs to be minimized or exploited. (R7) states: *“One reason for the occurrence of positive variation is that the time-estimates are not made realistic but conservative. The subcontractors make a conservative estimate to ensure that the deadline can be observed. And yes, this positive variation can be difficult to exploit.”* (R6) elaborates *“some of the problems caused by the over-estimating durations are removed in the process, because if you summarize the durations, you realize that the project overruns the deadline. It is therefore necessary to carefully trim the duration of the included activities.”* Thus, positive variation can be decreased if estimates of duration are determined more

realistically. Besides the realistic estimates, positive variation is caused by varying duration at site. Variation in duration is caused by the complexity and uncertainty within the construction process (Ballard 1999; Lindhard and Wandahl 2013c); which needs to be decreased.

According to Lindhard and Wandahl (2013c) positive variation can be exploited by; step a) ensuring that the crew finishing an activity before expected can continue their work. To ensure that the crew can continue their work their activity needs to be grouped and is thus an extra argument for keeping an even manning. Step b) ensuring that any connecting activities are able to start as fast as possible. The fulfillment of the two steps can be achieved by ensuring flexibility in the process, one approach could be by applying buffers but because of the associated cost buffering is a last resort (Lindhard and Wandahl 2013c). (R5) states: *“The problem occurs if it is not the same subcontractor who completes the subsequent activity. As a site-manager you have to follow how the construction process develops. If you discover that an activity is being completed ahead of schedule you need to communicate and coordinate these changes with subsequent subcontractors to exploit the gap. The bigger the project and the more subcontractors present the more complex this coordination task gets. The flexibility of the subsequent subcontractor is often limited by material deliveries. Thus, the more just-in-time your deliveries are the more difficult is it to exploit the gaps caused by positive variation.”*

3.6 Look-ahead schedule

The Look-ahead schedule is introduced in LPS to ensure that activities are sound when entering the Commitment Plans. When an activity enters the Look-ahead window a making ready process is launched. During the making ready process all preconditions are fulfilled to ensure that the activity can start and finish on schedule (Lindhard and Wandahl 2013a; 2012e). According to (R1) *“it is just as important that the following activity is starting on time as it is that the current activity is finishing on time. Nothing is as demotivating as rushing to finish on deadline just to discover that the subsequent subcontractor has implemented a buffer so that he does not have to start within the first three days”*. To avoid unfulfilled preconditions to be overlooked Lindhard and Wandahl (2012e) categorize the preconditions into nine main categories: 1) Known conditions, 2) construction design and management, 3) components and materials, 4) workforce, 5) equipment and machinery, 6) working conditions, including space, 7) connecting works, 8) climate, and 9) safety, and thereby expanded the traditional conception of seven preconditions, cf. Koskela (1999). Communication and collaboration among contractors and site management is an important part of the making ready process and increases both schedule quality and conflict awareness (Lindhard and Wandahl 2013a). (R2) underlines the importance of collaboration *“The making ready process is not just an individual process. The making ready process has to be ongoing in collaboration among the present subcontractors”*.

The making ready process should in accordance to the mindset of Lean pursue optimal fulfillment of the preconditions to increase productivity within the completion process and to minimize the likelihood of negative variation which results in delay (Lindhard and Wandahl 2013a; 2013b; 2013c). Thus, the presence and the quality of the fulfillment of every precondition are important (Lindhard and Wandahl 2013a). When all preconditions have been fulfilled the activity is moved to a buffer of ready work. At risk activities, see Liu and Ballard (2008), are buffered separately in a at-risk buffer until the activity enters the Commitment Plan or the risk is eliminated (Lindhard and Wandahl 2013b). If the risk is eliminated the activity is moved to the buffer containing ready work, cf. the arrow on Figure 1.

Buffering creates a link between the Look-ahead schedule and the Commitment Plans, where ready or at risk activities are selected from the buffers to fill the work plans with sound work (Lindhard and Wandahl 2013a). According to Lindhard and Wandahl (2011), *“Every precondition is a variable and composes a possible obstruction for a given assignment to be fulfilled.”* Buffering increases process adaptability and thereby minimizes the effect of “error” by maintaining a constant workflow (Lindhard and Wandahl 2013a). In relation to LPS theory the buffer should be kept at two weeks work (Ballard 2000).

The pace of the making ready process needs to be kept high and congestions avoided to continuously feed the Commitment Plans with ready activities (Lindhard and Wandahl 2012b). The risk of congestions can be reduced by minimizing task and trades on-site (Lindhard and Wandahl 2013a; 2012b), this can be achieved by increased usage of prefabrication, preassembly, or modularization. Ideally problems should be caught at the root. Therefore, the key rule when avoiding congestions in the making ready process is that activities if possible should be fit to capacity and not capacity to activities (Lindhard and Wandahl 2012b). Thus, lowering the manning will fit capacity to activities and thereby slow down the production resulting in delay and waste, cf. not exploiting the capability in the construction system was earlier mentioned as the 8th source to waste. The buffer of next week’s work helps in absorbing undesired variation when making work ready. Lindhard and Wandahl (2012b) suggest that the existing buffer should be supplemented with flexible buffer activities, cf. (Echeverry *et al.* 1991). Flexible activities are not tied into the sequence and can therefore be stored in the buffer until needed. Bertelsen (2003b) elaborates: *“Many projects activities are not inter-dependent and may be executed in any sequence or even simultaneously without any effect on the overall result.”* Therefore, using flexible activities as buffer activities can handle variation without affecting the future sequence (Lindhard and Wandahl 2012b). (R4) is applying flexible buffers: *“Our buffer contains activities which can be completed when the work else is interrupted; for instance due to rainy weather”*.

3.7 Commitment Plans

Production control is grounded on commitments; the quality of the schedule is depending on the quality of the settled commitments (Lindhard and Wandahl 2013b). At the point when an activity enters the Commitment Plan a binding commitment is made. (R1) elaborates: *“It is crucially important that the site-manager is prepared to the meeting and knows the construction stage and the impact on sequencing, critical path, and the other selection characteristics and is capable of drawing lines back to the previous plans. If these lines are not drawn there is actually no reason for conducting Phase Scheduling. If the sequence is changed the site-manager has to ask the critical questions to why these changes and adjustments are made. To do so, you will need to be prepared”* and continuous *“Even though you are prepared and know the process you want on beforehand, you still have to be open for changes and for details you might have overlooked. You need to allow the craftsmen to influence the process to ensure ownership to the schedule”*.

In the search for improved schedule quality the commitments have to be settled in mutual agreement and with the best possible information on hand (Lindhard and Wandahl 2013b). To procure the information the schedule has to be updated to reflect the construction site’s current situation. Based on the completion stage of the individual activity adjustments in the schedule has to be made to avoid any upcoming conflicts in handoffs. Moreover, since the fulfillment of a precondition can change, a health check of the buffer should be implemented (Lindhard and Wandahl 2011). Thus, the health check does minimize the likelihood of non-ready activities entering the Commitment Plan (Lindhard and Wandahl 2013c). By detecting changes

on beforehand adjustments can be made to avoid conflicts between handoffs and to increase schedule quality and reliability (Lindhard and Wandahl 2013b; 2011).

The output is the guideline for the updated schedule. The final schedule is archived by reincorporating the six preconditions into the schedule, i.e. the same parameters which were applied to refine the network chart at the Phase Scheduling level. The six relevant preconditions include: Machinery; material; and workers, which comprise the needed resources, and working conditions; climate; and safety, which affect the pace of the work (Lindhard and Wandahl 2013b). (R3) states that *“at the Commitment Plan level you know your flows, and the current situation, you do not adjust the flows you just coordinate in relation to the given parameters”*. According to Lindhard and Wandahl (2013b) the key points to go through are:

3.7.1 Machinery

“Update and link shared equipment and machinery to each activity to ensure availability. Group the activities, in relation to machinery usage, to improve utilization rates. Evaluate the maintenance and consider the effect of the emergency plan and continuously seek for improvements.”

3.7.2 Material

“Update needed material to each work activity and check for material availability. Consider site logistics and continuously seek for improvements.”

3.7.3 Workers

“Make the final decision regarding the needed workforce to each activity and calculate next week’s manning. Aim towards a steady manning throughout the entire construction project. Consider the effect of initiatives implemented, to improve the comfort of the individual craftsman, and continuously seek for new ways to improve them.”

3.7.4 Working conditions

“Update working areas and space requirements to each activity. Ensure that space is available by linking usage to the schedule. Consider the effect, of the initiatives implemented to improve the working comfort, and continuously seek for new ways to improve them.”

3.7.5 Climate

“Consider the implemented climate precautions and scenario plans and update if relevant. When scheduling next week’s work, use weather forecast to keep track of the short-term effect of the climate parameters. Constantly follow the weather and act if critical changes occur.”

3.7.6 Safety

“Consider the selected safety precautions to the individual activity, and follow-up by site monitoring during the completion phase. Act immediately if anything critical is detected to hinder accidents in developing.”

By systematically integrating the procured information into the schedule, relevant changes are made and the quality of the commitments is increased as is the quality of the Commitment Plans which is the output of the process. Increased commitment quality decreases the likelihood for changes in the schedule which

due to a complex and changing environment cannot be completely avoided (Lindhard and Wandahl 2013d). Lowering the risk of changes in the schedule makes the schedule trustworthy and reliable and most importantly binding for all project participants (Lindhard and Wandahl 2013d). If the plan is continually changed it loses its credibility and in worst case execution is separated from planning” (Koskela and Howell 2001).

Interruptions and conflicts in scheduled activities make it necessary to focus on creating soundness awareness, in an attempt to spot emerging conflicts as fast as possible. The soundness awareness is supplemented by a set of actions to handle the conflicts. As a part of the action plan, buffering of sound activities is applied. If a non-sound activity is discovered the activity is replaced with an activity from the buffer of ready work. Selection of the replacement depends on activity “*characteristics*” where all relevant parameters are considered, this includes: durations, interdependencies, critical path, slack, safety, climate, working conditions, workers, material, and machinery. Communication and collaboration are important to secure an optimal handling of arisen conflicts (Lindhard and Wandahl 2012g). According to Lindhard and Wandahl (2012g) it takes “*teamwork to work around the changes to find and exploit new possibilities and to optimize the process*”. Furthermore, communication and collaboration between the project participants are essential to avoid misunderstandings when implementing the changes (Lindhard and Wandahl 2013a; 2012g).

3.7.7 *Coordination Schedule*

To support communication and coordination on-site a second output to support the Commitment Plans is a Coordination Schedule. This schedule contains interrelationships and bonds between the activities. Moreover, it contains a list of relationships and the needs for coordination, together with the one responsible. Thus, applying a Coordination Schedule is supporting a decentralization of responsibility and force and supports the subcontractors to communicate. Moreover, a Communication Schedule is, by structuring the needs of and clarifying the lines of communication, simplifying coordination on-site. According to (R6) “*a good construction site is a site where coordination and communication works, all too often communication fails*”. This is why (R5) states: “*It really makes sense to force and support the communication; definitely*”.

3.7.8 *Daily Look-ahead Planning*

Daily Look-ahead Planning is implemented as an extra element to identify and handle sudden conflicts. Conflicts are identified by briefly checking up on the soundness of the scheduled activities. Implementation of a daily health check is proposed by Lindhard and Wandahl (2013e), who argue that the health check will help to identify conflicts earlier and thus when there still is time to make small adjustments. Thus, by identifying conflicts on beforehand critical interruptions and stops in the workflow are avoided possibly bringing productivity up. Identified non-ready activities are replaced with ready activities from the buffer where activity “*characteristics*” once again are decisive. (R6) explains that “*it is normal to do a round at the site in the morning, to check that you have every piece you need in the production. At any rate, it is a good thing to do*”. (R1) elaborates: “*In the morning the foremen schedules the work day, in consideration of the present workforce and materials. Changes in the conditions, is why we experience changes in the Commitment Plan. But I think it is a good idea to formalize it*”.

3.7.9 Follow-up

Halfway through the week, the site-manager does a round on-site to follow-up on the commitments in the Commitment Plan. (R2) elaborates *“if anything critical is observed it is in a mutual agreement settled how to intervene to ensure that the activity can finish on schedule”*. If the site-manager realizes that an activity is being completed ahead of schedule the site-manager needs to communicate and coordinate changes with subsequent subcontractors to secure that the gap is exploited. (R1) elaborates: *“Actually, I think it shows seriousness that the site-manager does rounds on-site and follows the progress in the work. Thus, before the scheduling meeting I already know which activities did and did not finish on schedule, and I have already talked to the subcontractors and obtained an explanation”*. Making observations and doing rounds on-site is supported by (Samudio *et al.* 2011) which apply “going and seeing” as a tool to collect data to make adjustments to “continuously improve production and increase the reliability of Commitment Plans”.

After completing the work-week corresponding to the Commitment Plan, output quantity and quality are controlled. In Figure 1 this is marked as the follow-up process, which gives input to the schedule update. (R7) states: *“In my opinion, the follow-up process, including the PPC registration and calculation, should not take place at the scheduling meetings. At the scheduling meetings we shall not look backwards, but forward”*.

LPS is only focusing on the conduction of the schedule and schedule reliability or quality, the schedule quality is measured by the PPC-measurement (Lindhard and Wandahl 2013a; 2011). (R3) states: *“In my opinion LPS is a scheduling tool, and should therefore only consider the schedule and not quality. Quality is of cause relevant but I do not think that it should be handled by the scheduling tool”*. According to Lindhard and Wandahl (2011) a clear picture of performance is only achieved when the effect of poor quality and defects are deducted from the initial performance. (R5) supports and states: *“I do absolutely agree quality should be deducted from the PPC. If the focus on quality is enhanced, the hours spent on rework could be reduced”*.

It is a risk that the PPC-measurement is perceived negatively, because the focus is on non-completions and not kept agreements. According to (R1) *“the PPC measurement can easily appear to be outrageous accusingly. You need to create a positive atmosphere at the meetings.”* (R7) elaborates *“it is not funny to be scolded at every scheduling meeting because of not kept commitments and continuously to be asked why. Sometimes we need to look at the positive aspects”*. (R5) agrees and elaborates *“sometimes it is important also to focus on the positive experiences to pass them on in the construction process.”* (R4) relates the feedback process to the Re-scheduling and states *“Instead of checking whether the activity was completed or not, I want to check how it was completed. To see, if there is something to learn, both positive and negative, and thus something in the upcoming process which need to be adjusted. We keep repeating the same mistakes. It could easily be combined with a general procedure for experience gathering.”*

3.7.10 Measuring Performance by calculating manHours (MPH)

The PPC-measurement can be used as an instructive predictor to performance in terms of output quantity. To enhance the quantity measurement, the consumption of man-hours to each work activity is calculated and compared to the hours completed in the schedules. Potential delay in man-hours can be calculated by registering the missing compliance of man-hours. A man-hour status can be calculated by summing positive and negative variations in output. By comparing the man-hour status with the Master Schedule a time

status can be calculated. Calculating performance per activity makes it possible to follow the activities. (R5) *"In my opinion, this is a good idea. Today we already at a weekly basis calculate used man-hours and compare it to the hours completed in the schedules. By doing it at activity level I could actually follow the activities, it makes it easy to reveal if an activity suddenly starts to consume extra time."* (R7) elaborates: *"As a part of our economical follow-up, we do every fortnight or every month evaluated our activities. Then you have every activity and can see the time consumption in the period. From this you can calculate the stage and compare it to the anticipated stage. As a site-manger you decide the level of detail. As part of the same procedure you can easily calculate time- and material usage, utilization of machinery, space and workforce etc. Afterwards you can look into the root-cause to the deviations to reveal if it is caused by waste in the work process or just an erroneous calculation"*. (R6) elaborates *"Repeating work activities should normally be conducted faster and faster. If you keep an eye on time usage on repeated activities and realize that time usage is increasing you need to determine why. This would make sense."* And (R7) elaborates *"If time usage is increasing, you know that something is wrong"*. (R1) points out *"In my opinion, you need to consider how much energy you will spend on the calculations; a lot can be learned just by talking to the subcontractors. The subcontractors will probably know the problem and the sources to the waste."* The MPH measurement is illustrated at Figure 8.

3.7.11 Measuring quality

Output quality is important. A clear picture of performance is only achieved when the effect of poor quality and defects are deducted from the initial performance. Rework can be used as an indicator for unacceptable quality, and hours spent on rework can be added to the MPH calculation. If a more nuanced evaluation of the quality is considered important a quality control check should be implemented in a handover process between handoffs. The quality control check could be undertaken by either site management or the successive work crew (Lindhard and Wandahl 2011). This is supported by (R2) who

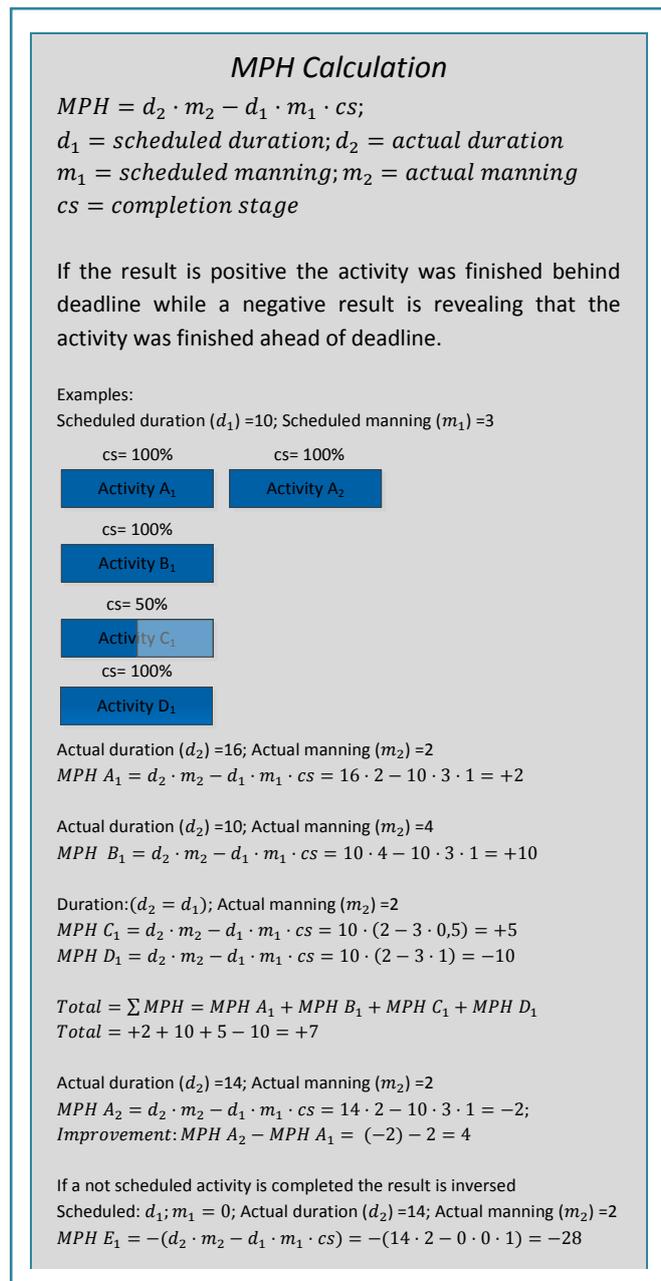


Figure 8: Calculating MPH.

elaborates: *“Productivity is related to the quality of the executed work. We have implemented a handover process, where the performing- together with the subsequent subcontractor evaluates the quality. The handover process enhances the quality awareness”*.

3.7.12 Learning

Continuous improvement is a central part of Lean Construction. In the PC⁴P framework this process is called the learning process. The Re-scheduling process provides feedback at the Phase Scheduling level while the Learning process accumulates on-site experience and serves as feedback to the Look-ahead Schedule and the Commitment Plans. In LPS learning is achieved by registering if the activity was completed on schedule, and if not identifying root causes to avoid repetitions. In the PC⁴P framework, the Learning process is a part of the site manager's rounds on-site, where conversations with the men on-site are essential. By discussing the current progress and looking into how the activity is completed, both positive and negative experience is gathered. The lessons learned helps in adjusting the upcoming process and to continuously improve. Negative experience, which surfaces as conflicts and non-completions is reduced by tracking down root-causes to avoid repetitions. Moreover, understanding the triggers can help in predicting future conflicts (Lindhard and Wandahl 2012g). Positive experience, which surfaces as genius solutions and ideas, is preserved through reflection and discussions to understand and accumulate the experiences. When making an activity ready, relevant experiences both negative and positive can be found in a log, this increases awareness to both negative and positive learnings and the result is increased continuous improvement.

4. Conclusion and recommendations

Due to the complex and unpredictable nature of the on-site construction process, production control is the art of the impossible. Multiple approaches have tried to control the process to eliminate the risk of time and cost overruns, but still none succeeded. A recent approach is the lean based production control tool LPS. Researchers within the field have since the late nineties published positive test results of the LPS approach. Despite the positive test results LPS does still not handle the construction process perfectly. Thus, construction projects are still facing perceptible problems such as: cost and time overruns, inadequate communication and collaboration, errors, defects and rework and low productivity. Even though improvement is needed, only little critique of LPS exists. Critique is necessary for improvement to occur. Therefore, in the search of excellence the following research hypothesis was raised:

Production control in on-site construction can be improved; this can be achieved by improving the efficiency and effectiveness of LPS.

By looking into the current situation at on-site construction it was verified that production control in on-site construction can be improved. Errors were found to be significant. Moreover a lot of concomitant problems were registered: waiting, motion, cleaning, rectifying etc. which resulted in time- and cost overruns and chaos (Love 2002). Thus, errors induced negative variation in the execution process, and were subsequently registered as leading to low quality and rework resulting in an even more unpredictable, complex and chaotic construction process. Today's production control systems are neither able to reduce or handle errors nor able to reduce the concomitant problems to avoid the associated time- and cost overruns.

The second part of the hypothesis expressing that improved production control can be achieved by improving the efficiency and effectiveness of LPS has been verified by studying both theoretical and practical application of LPS. Efficiency is achieved by improving the schedule itself while effectiveness is achieved by improving the process and flows outside the schedule. To utilize the untapped potential of LPS it has been necessary to find answers to how increased efficiency and effectiveness can be gained. In the search for improvements in LPS specific areas have been revealed and several points of criticism have been raised to the existing production control system. Based on the point of criticisms an improved production control system has been developed.

The contribution of the Ph.D. project is a new framework for Production Control in Complex and Constrained Construction Projects (PC⁴P). The impact of the new production control framework is considered important. Production control is crucial in the attempt to improve the performance in on-site construction. One reason for improving the performance of on-site construction is the impact on macro economy (Lindhard and Wandahl 2012a). In most countries the construction sector does account to approximately 10% of the GNP (Seaden and Manseau 2001). Therefore, even small improvements in the construction sector will have a noticeable impact on the GNP (Bertelsen 2004; Wandahl *et al.* 2011). Besides the macro economical aspect, production control is important to decrease the risk of time and cost overruns in construction. Improving production control will reduce variations in cost and time and thus make the schedules more reliable. The PC⁴P framework is presented in chapter 3 Exploring for excellence within Last Planner System. Thus, only a brief presentation of the changes is summarized in the following.

First of all the framework has, by adapting an open system-theory mindset, been expanded to include the external environment. The external environment is considered important because it influences both behavior and processes (Hartley 2004). Behavior is crucial in relation to application of the PC⁴P framework but also regarding the quality and quantity of the output. Behavior can be affected by: comfort, motivation, and mutual trust. It was found that Leadership and ethical values can be used as tools to foster and support behavior. The scheduled process is crucial, it determine what is conducted at site and when. Thus it is important to notice that the construction process is affected by the complexity and the adaptability of the production setup.

Flows and CPM consideration have been added as criteria when selecting activities to the schedules. Thus, to increase schedule quality, the existing selection criteria (duration and interrelationships) have been expanded. When analyzing the flows only six out of nine flows were found relevant as selection criteria. The six flows are as follows: machinery; material; and workers, which comprise the needed resources, and working conditions; climate; and safety; which affect the pace of the work (Lindhard and Wandahl 2013b). Concrete recommendations on how to apply the six flows can be found in the presentation of the framework in chapter 3.

The making ready process is changed to not only secure that activities are ready but to pursue an optimal fulfillment to the preconditions. Now both the presence and the quality of the fulfillment are regarded. By pursuing optimal fulfillment, productivity within the completion process is increased and the likelihood of delay minimized. Because variation in the fulfillment occurs, the soundness of buffered activities is inspected through a health check just before conducting the Commitment Plans. The health check minimizes the likelihood of non-ready activities entering the Commitment Plan and thus increases the robustness and quality of the schedule.

Another approach to increase schedule quality is the implemented Re-scheduling of the Phase Schedule. At carefully selected and repetitive task the scheduling process is redone. By returning to the scheduling phase process, positive and negative experience can be discussed, and overlooked sub-activities and problems can be incorporated into the schedule to improve the sequence. Moreover, Re-scheduling could be combined with traditional waste reduction.

In an attempt to foster on-site communication and collaborations a Coordination Schedule was implemented at the Commitment Plan level. The schedule, which was implemented to structure the needs and clarify the lines of communication, contains interrelationships and bonds among the activities, the needs for coordination and the one responsible.

To avoid interruptions in the workflow conflicts need to be identified as early as possible. To increase conflict awareness Daily Look-ahead Planning was implemented. At the Daily Look-ahead level conflicts are revealed by briefly checking up on the soundness of today's activities. Identified non-ready activities are replaced with ready activities from the buffer where the expanded selection criteria are decisive.

Finally, the follow-up process has been changed. It has been recommended that the site-managers do rounds on-site to follow-up on the production. Thus, the on-site status should be known before initiating the Commitment Planning. Knowing the status on beforehand enables the site-manger to make preparations. After completing the work-week corresponding to the Commitment Plan, output quantity,

quality, and delay are controlled. A clear picture of performance is only achieved when viewed together with quality of the output. It is suggested that quality control checks are undertaken by management or the successive work crews. Furthermore, rework can be used as an indicator for output quality.

To enhance the quantity measurement it is suggested to calculate and follow the amount of man-hours used pr. activity. By comparing with the scheduled man-hours possible delay can be calculated and by following time usage on activity basis it is easy to register changes if an activity suddenly starts to consume extra time, e.g. decreased productivity. Moreover, the calculations can be extended to include material usage, utilization of machinery, space and workforce etc.

Learning is expanded to include both failures and success to minimize failure and to maximize success. This can be achieved by, instead of looking at if the activity was completed on schedule, looking into how the activity was completed, and thus both consider the negative and positive experience.

3.7.13 Delimitations to research findings and future research

The research published in the presented papers is primary based on a qualitative approach, with a limited number of cases and interviewees. Even though the results are generalized the cases do not cover all different categories of construction projects, only housing and refurbishment projects are followed. Other categories of projects could for instance be road or offshore projects. Besides the limitation regarding project category, the study is limited to take place in either Denmark or in the US. Thus, only cases or respondents from Denmark or US are participating in the study. The developed framework is based on the critique revealed in the published papers. The framework has not been tested on-site but only been validated by a limited group of experts whose feedback positive as well as negative has helped in improving the PC⁴P framework.

Continuous improvement is still important in order to achieve excellence. Therefore, to strengthen the research results more case studies could be followed to increase the data basis. If more cases are followed, the study should be expanded to include different categories of construction projects such as road or offshore projects. Simulations could be applied to measure performance, and to enable comparison between different production control approaches, both computer simulations and practical simulations could be applied. Moreover, application of the PC⁴P framework should be tested on-site. Testing of the framework is not only for verification but also to challenge and critique and even change the system in order to continuously improve.

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Appendix A: The appended papers

The appended papers comprise the second part of the thesis “Exploring the Last Planner System in the Search for Excellence”. The appended papers serve as documentation to the research findings. A short summary to the main contribution is presented in the cover. The papers have been published individually at relevant journals and conferences. Thus, repetitions between papers must be expected. Moreover, the layout varies this because the papers are presented in their original layout.

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Handling Soundness and Quality to Improve Reliability in LPS – A Case Study of an Offshore Construction Site in Denmark.

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Abstract:

The Last Planner System of Production Control (LPS) is, in today's construction projects, a common used tool to secure a reliable planning. Even though LPS is an efficient system to keep track of the production, and a remarkable increase in productivity has been achieved; the system is not perfect. In order to gain further productivity improvement, elements in LPS have, therefore, been analyzed. This includes both the elimination of preconditions, defects, and quality issues which among others are affecting the time schedule. To determine if defects and low quality is substantial in construction, empirical data was collected and compared with previous studies. This showed that cost and time consumption related to rework, caused by defects and low quality, is significant. Rework is impossible to forecast, and it affects the time schedule, and decreases reliability and predictability. Quality has in LPS only minor direct attention, but in an attempt to increase reliability defects and quality has to be taking into account. In general the construction site is complex, dynamic and uncertain why one wonders why the "health check" when eliminating preconditions only is performed once. Because the soundness of each precondition easily can change, it brings uncertainty into the backlog of sound assignments. An approach to increase reliability is to expand the PPC measurement to include quality and by introducing a "health check" of the buffer as an addition to the conduction of the Weekly Plans.

Keywords:

Defects, Last Planner, Precondition, Quality, Waste

1 Introduction

Through this research there will be a focus on the defects and errors which surfaces during the construction process. The defects and errors consist of problems, inconvenience, mistakes, breakdowns etc. All the mentioned factors are affecting the time schedule, and are decreasing the reliability and predictability of the construction process. By determining the magnitude of defects and errors it can be concluded whether or not these problems are general in construction and if the related extra cost and time consumption are significant. The study reviled that cost and time consumption are significant, therefore, preventive actions have to be carried out, to help the construction industry in handling the mentioned problems.

To prove that defects and errors are a general tendency in construction and not just an isolated incident, previous studies are included. By including other studies the quantity of data is much greater.

The Last Planner System of Production Control (LPS) is a scheduling tool developed to increase the reliability of the schedule and thereby handling errors and defects which occur during construction. Ballard (1994) who introduced LPS also introduced a tool to measure the reliability of the schedule called PPC.

Before Ballard introduced the LPS, he measured the PPC level to be about 50 %, after implementation he recorded the PPC to be at the 70 % level. Furthermore he measured a decrease in non-productive time on 15 % from 50 % to 35 % (Ballard 1999). Here non-productive time only included the loss of productivity which can be assigned to delays and rework

Indeed there is still, both reliability in planning and more essential productivity to be achieved. Still 30 % of all planned activities do not finish as planned and still only 65% of all time is productive. The question is what can be done to improve the LPS, in the handling of defects and errors. Two issues are treated; the making ready process, and the purpose of the PPC.

The making ready process is extremely important; through this preconditions are removed. This is done from every individual assignment and if the making ready process fails, the assignments cannot be executed. But changes in preconditions take place (Love 2002). In this research, a weekly “health check” is therefore proposed to ensure nothing goes wrong.

The reason to introduce the PPC measurement was to measure the reliability of the schedule, to be able to react on variations, and to find and eliminate root causes. By only measuring the observance of the schedule, the quality aspect of the completed work is neglected. Therefore this research proposes that a quality aspect is added to the PPC measurement. The reason why, is that a completed assignment is very depended on quality. Increased quality also means reduced time spend on rework.

1.1 Elucidation of the extends of defects in construction

The costs of defects and errors during the construction process have been a popular objective for research in decades e.g. (Hammerlund *et al.* 1990b). A brief historical view to these studies points out that it is a general problem which usually amount to a considerable part of the total project costs (Burati *et al.* 1992). The costs of defects or errors can be divided into direct and indirect costs. The direct costs are the direct measurable costs attached to a given defect. The indirect costs are not directly connected to correcting the defects or errors and are, therefore, not directly measurable. The indirect cost or consequence of an error is multiple. Peter Love categorizes the consequences of errors into three groups which all attribute to cost at different levels in the company (Love 2002).

- *At the individual level*, stress, fatigue, absenteeism, de-motivation, and poor morale are found to be the primary indirect consequences of rework.
- *At the organization level*, reduced profit, diminished professional image, interorganizational conflict, loss of future work and poor morale are identified as indirect consequences of rework.
- *At the project level*, work inactivity (e.g. waiting time, idle time, travelling time etc) and end-user dissatisfaction are identified as indirect consequences of rework.

Cited from (Love 2002)

The results of the selected studies are presented in the text below.

Back in 1990 Hammalund *et al.* (1990a; 1990b) conducted a study of quality failure costs. The study included one main site which was monitored spanning over a 20 month period. To test the validity, 21 small building sites were monitored in a 3 week period. The study revealed that the costs of correcting the quality failures amounts to 6 % of the total production costs.

Burati *et al.* (1992) monitored the cost of quality deviation from nine construction projects. The collected data did include the direct costs related to rework, and cost of rework associated with design changes. Burati *et al.* found that the costs of rework on the nine projects varied between 0.4 and 26.0 % of the total project costs resulting in an average cost at 12.4 %.

Through studies performed from 1994-1996 Josephson and Hammerlund (1999; 1994) monitored seven different construction projects to ascertain the causes of defects and the related costs. The studies showed that the costs of defects varied between 2.3 and 9.4 % of the total production costs, this only including the direct costs of the defects.

In a research conducted by Abdul-Rahman *et al.* (1996) the costs of non-conformances on constructions sites were measured to be 6 % of the total project costs. Here a single construction site was monitored during a 22 week period. Non-conforming costs include costs of rework, material waste, warranty repairs etc. while conformance costs include costs of training, indoctrination, verification, validation, testing, inspection, maintenance, audits etc. (Love and Li 2000).

Love and Li (2000) studied the courses and costs of rework at two Australian construction projects. This revealed a cost of rework at respectively 3.2 and 2.4 % of project contract value. Even though the study only included the direct costs, Love and Li (2000) stated that the results were not to be considered indicative. This mainly because the costs were significantly lower than indicated by previous studies.

In 2000 Barber *et al.* (2000) measured the costs of quality failures in two major road projects. Only the direct costs of failure were observed. The findings showed that the costs of failure were respectively 3.6 and 6.6 % of the total project costs. To this Barber *et al.* (2000) afterwards added the calculated costs of both delay and work acceleration

resulting in a significantly higher loss at respectively 16 and 23 % of the total project costs.

In Denmark Apelgren *et al.* (2005) during a three months period studied the amount of stumbling stones in a housing construction. Where the term, stumbling stones, is defined as: All conditions in the product or process which prevents the entrants in conducting his work as effective and correct as possible – the first time (Apelgren *et al.* 2005). The findings showed that the amount of stumbling stones amount to 7 % of the total contract sum. The result includes both the direct and indirect cost; it is though a conservative estimate to the costs of stumbling stones. This is primarily due to limited resources to the registration of stumbling stones and to difficulties in determining the extent of the indirect costs. Design changes are not included in the study.

All the mentioned studies include only the direct costs related to rework or errors, this except Apelgren *et al.* (2005) who also have included a conservative estimate to the indirect costs. The direct costs are according to Burati *et al.* (1992) only the “tip of the iceberg”. An study by Love (2002) states that the indirect costs are a significant expense, and have a multiplier effect of the direct cost at between 3 to 6 times. This agrees with Love and Li (2000) which state that indirect costs are a considerable part of the costs. The reason why only the direct costs are included is because it is very difficult to determine the indirect costs (Love 2002).

Wantakorn *et al.* (1999) studied management errors in construction. They concluded that no matter levels of skill, experience or training of the management, they can make errors at any time. Wantakorn *et al.* (1999) identified the following factors as affecting the frequency and severity of the errors: Task complexity, pressures of time and cost of project, and the uncertainty of the management task. They furthermore simulated the probability of management error in consideration of the mentioned factors.

Of course there is conducted more studies than those included in this short review. The included studies confirm that errors do occur, and they provide a basic knowledge to which extent errors occur. Since only the direct costs are included in the above mentioned studies, with the exception of Apelgren *et al.* (2005), the figures gives a very conservative bid to the costs of error in construction. However the studies do show that the costs of error represent a significantly part of the estimated total construction costs.

2 Research Methodology

This case study is in a four months period conducted at an offshore wind farm project in Denmark. The study is conducted in collaboration with the main contractor of the civil works. Because the construction site was placed at sea, the logistics and storage of equipment and materials took place with limited resources. Transportation was done by boat, and depending on the speed and the placement of the foundation, the transport time varied between 20 – 60 minutes.

The purpose of the case study was to A) prove that errors do occur and B) to find root causes to these problems in an attempt to increase productivity. The main research question throughout the study has been: How is it possible to improve reliability in order to increase productivity.

The data collection consists of primary daily observations and experienced problems. Here the observations are focused on problems related to soil surveys and excavations, where there on a regular basis has been contact with the main personnel. Additionally data was collected through unstructured interviews.

Only major problems which had a significant impact on the production were collected. In total 24 problems were registered. The observer was focusing on soil surveys and excavations. It is expected that not all major problems were discovered. Therefore, the survey does not give a complete picture of all experienced problems, but it leaves a good impression of the impact and the significance of problems in construction. Besides observations of problems, the everyday contact to the contractor gave a good insight in difficulties and complications which occur during offshore construction.

The data collection consists of a short description of observed problems. There is made no calculation of expected cost.

3 Empirical evidence

During a four month period, major problems in an offshore construction project were monitored. In total 24 problems were collected, all having influence on among others the time schedule. The problems are described in detail in (Thomsen 2010). There is made no calculation to neither the direct nor the indirect costs of the problems, but an offhand estimate clarify that the costs are significant.

Besides the monitored problems, other factors were having an influence on cost and on reliability. The weather in general had a great impact to the work performed, because it was changing the soundness of the scheduled assignments. This is why bad weather often was the cause to non-productive time, in a normal workweek this composed to, not only hours, but days. The number of bad weather days varied with the season, at summer it was one or two days a week, and at winter it was three or four days a week. The weather was very unpredictable which is why it was an obstruction to the planning and time scheduling. Even local weather forecasts had difficulties in predicting the weather and the time span of bad weather so accurate that scheduling by the hour made sense.

The weather made it with the tools available impossible to conduct a robust and reliable time scheduling. It affected both the working scheme and the duration of the assignments. Bad weather days completely stopped production at the construction site, where only maintaining activities could be conducted. Because of the weather the soundness of the assignments varies, which makes it impossible cf. LPS to maintain a backlog of ready work. Thus the assignments are not following the critical characteristics for a sound assignment cf. LPS (Ballard 2000).

Another factor which complicated the planning was the great distance to the construction site. Material, equipment, machinery, and labour; everything has to be transported by boat. With limited resources the logistics have to be planned carefully, changes in orders made it very difficult and often there was a lack of capacity. Moreover the transport took a lot of time, which besides non-productive time, made the production sensitive. If for instance there is a breakdown on some of the heavy equipment and a repairman or a specific spare part is needed, the transport time gives an increased delay in the production. Furthermore, the great distance made it difficult to follow up on the production, to verify the quality and to follow up on the planning.

Finally the study has revealed that construction managers work with high pressure and stress. The time pressure presses the construction managers to make fast and not thought through decisions. This gives an enhanced probability for the managers to make errors (Wantanakorn *et al.* 1999).

The conclusion after monitoring the project is that the construction process at offshore construction is very complex and chaotic and impossible to predict and plan completely. There is constantly a change in the daily plans which indicate the lack of a more flexible and robust planning.

4 Evaluation of the studies

The great variation in results from previous studies, can among others, be ascribed to the building process, which is complex and chaotic (Bertelsen and Koskela 2003; Bertelsen 2003). This is making it very difficult to register and measure the costs. There are a lot of factors that contributes to the great variation in the findings. Primarily there is a lack of uniformity in the way data is collected; this includes the used sources such as observations, interviews and other documented sources from the site. This non-uniformity is reflected in the huge difference in the factors which are included in the studies. Furthermore, the objective of the studies is often different, some are focusing on measuring the cost of errors some quality failures, some non-conformance and some the amount of rework. Generally there is a lack of guidelines on how to perform the study and there is no given interpretation of which factors there should be included in the studies.

Despite differences in data collection all studies shows that the related cost of errors are significant. Furthermore, there is accordance between the presented theory and the empirical data collected from the case study. Therefore it can be concluded that errors are a general problem in construction.

Errors or rework are directly effecting the conducted planning. The errors cause non-productivity which include waiting, motion, cleaning, rectifying etc. and are thus a main source of time- and cost overruns and chaos (Love 2002). Love and Li (2000) found that rework have a major effect in the time performance. He measured two construction projects and found that rework had an unfavourable effect on the critical path at

respectively three and four weeks. Furthermore errors do provoke defects which induce increased costs and decreased quality and productivity.

To avoid delay and daily penalties, time overruns are often handled through accelerated work. Barber *et al.* (2000) pointed out that accelerated work usually is significantly more expensive than work completed at normal tempo. Randolph and Todd (1996) surveyed 129 different electrical contractors to measure the magnitude of inefficiencies due to overmanning. They found an average loss of total efficiency on 29 % which could be attributed to overmanning introduced to speed up production. They also found that the general trend is that the net loss of efficiency increases if the percentage of overmanning increases. The relation between schedule acceleration and losses in efficiency is supported by (Thomas 2000). Thomas surveyed three different construction projects and found that the estimated loss in productivity caused by accelerated work to be 25 %. He furthermore measured the loss in labor efficiency to range between 20 % and 45 %.

Errors are increasing the variation in execution of activities, and cause defects which subsequently lead to low quality. This result in rework which again makes the construction process unpredictable and chaotic. This unpredictability is making it very difficult to especially perform long term scheduling.

5 Improvement of LPS ability to handle soundness and quality

Rework, defects, errors and non-conformances all refers to problems or difficulties which occur at the construction site. And yet difficulties occur; Bertelsen and Koskela (2004) express it severe: *“The plans and schedules present an idealized linear picture of what should take place, but not of what actually dos take place. Planning does not reflect reality, but dreams!”*

The LPS works with a parameter PPC, which is a measurement showing in percent how many of the scheduled activities which are actually completed. In a typical construction site only half of the activities in the weakly plans, get conducted as planned (Howell and Ballard 1995). According to Ballard (1999) the implementing of LPS has raised the work flow reliability from 30 - 60 % to the 70 %. Though high PPC has been gained after implementing LPS, there is still a need for a more reliable and robust plan (Ballard 2000). To reach PPC at 90 % or higher additional actions are required (Ballard 1999).

According to the LPS theory the soundness of a certain assignment depends on seven preconditions which have to be present for an assignment can be conducted, first presented in Koskela (1999), but widely cited, among others (Bertelsen *et al.* 2006; Koskela 1999). The preconditions are as following:

- Construction design; correct plans, drafts and specifications are present
- Components and materials are present
- Workers are present
- Equipment and machinery are present
- Sufficient space so the task can be executed.

- Connecting works, previous activities must be completed
- External conditions must be in order.

If just one of the seven preconditions is not fulfilled the assignment cannot be conducted. Therefore it is extremely important that assignments do not starve any of the seven inputs. Koskela (1999) continues by stating that “*the realization of tasks heavily depends on flows, and the progress of flows in turn is dependent on the realization of tasks*”. The varying nature of Planning and scheduling can be difficult because these flows often are plagued by missing inputs and varying nature (Koskela 1999).

To secure a more robust scheduling a Lookahead process is introduced in the LPS. The Lookahead process is a plan spanning 3-8 weeks and which purpose is to remove constraints to secure the soundness of the assignments. Only sound activities are later moved to the Weekly work plan or to a buffer to maintain a backlog of assignments which can be performed (Hamzeh *et al.* 2008; Steyn 2001; Ballard 2000).

By securing that only sound activities are selected to the Weekly Work plans the success rate of completed tasks (PPC) is increasing. This entails that the uncertainty of the schedule is significantly reduced (Jang and Kim 2008; Ballard 1997; Ballard and Howell 1994). This increases certainty and honesty in the construction process, where “*we do what we say we are going to do*” (Ballard 1994). Furthermore a reduced uncertainty in the schedule leads to reduced project duration and costs (Ballard 1997).

Based on the case study two aspects of LPS are treated in an attempt to develop and improve LPS and thereby increase the reliability and robustness of the scheduling. The two aspects are first the making ready process with focus on changes in soundness, and secondly the purpose of the PPC measurement with focus on quality.

5.1 Changes in soundness

This process of removing constraints and making assignments sound is very idealistic. The “health check” is only performed once; it does not take in consideration that the soundness very well can change. A change in just one of the seven preconditions is enough. For instance would design changes, rotten and dwindling materials, illness, breakdowns, unauthorized storage of materials, delay of previous activities, or troublesome weather conditions all give rise to a change in soundness of an assignment. Conclusively every precondition are hereby a variable and compose a possible obstruction for a given assignment to be fulfilled. Still the likelihood of change in a precondition varies. For instance changes in construction design are expected, according to Love. This is because the clients have difficulties with the visualization of the end product that they procure (Love 2002). New 3D tools can help the customer in defining criteria and thereby decrease the number of changes.

According to the PPC problems, with not sound assignments, shall be registered, investigated and the roots afterwards eliminated, this is done to achieve a higher PPC. Firstly the roots can be very difficult to eliminate and control, especially concerning the external conditions such as weather conditions. Secondly, there is no assurance that every non-completed assignment is registered. If for instance a craftsman has to use a

buffer assignment, but finds that it at present time not can be conducted. Then the craftsman has a choice; A) report it to management or B) say nothing and find another assignment. If the change in preconditions is more permanent he could without telling choose to put the assignment back in the Lookahead plan.

At extreme construction projects a single or more preconditions can be very uncertain and uncontrollable. This will result in Weekly Work plans which at times contain not sound activities. In such constructions this precondition could be ignored. This could for instance be offshore works which are very dependable of the weather conditions. By ignoring the weather conditions cf. the example; the planning could be conducted as normal, but maybe with an extra focus on having a backlog with sound and weather undependable activities if possible.

The risk of changes in preconditions increases with time. Often many preconditions are fulfilled weeks before the assignment is planned to be conducted, leaving plenty of time for changes. To detect changes in preconditions it is proposed to implement a weekly “health check”. Changes in preconditions will now be detected beforehand, which will keep the production running unaffected and thereby increase the reliability and robustness of the schedule. The weekly “health check” can be implemented as essential part of the weekly PPC evaluation.

5.2 Handling quality

One of the central elements in Lean is the focus on product flow and in the elimination of non-transformations or non-value adding activities; in other terms the removal of waste. Ohno (1988) stated that the total capacity of a production system equals the sum of work and waste, he furthermore identified seven different types of wastes, these are showed at the list below; see also (Suzaki 1987). In the list the first five elements refer to the material flow while the two last refer to the human work flow (Koskela 2000).

- Waste of overproduction
- Waste of stock on hand (Inventory)
- Waste of transportation
- Waste of making defective products
- Waste of processing itself (Over-processing)
- Waste of movement
- Waste of time on hand (Waiting)

There are a lot of different reasons to why waste arises. Defects are resulting in waste. When work assignments cannot be conducted as a result of defects, it results in crew waiting time, crew motion and unnecessary transportation of material and equipment. This is reducing productivity and could subsequent lead to delay, and thereby affect the time scheduling. But most importantly defects result in low quality which force rework to take place.

Rework, which is very difficult to forecast, is by Love and Li defined as the unnecessary effort of correcting construction errors (Love and Li 1999). This often induces demolition or removal of the defect or damaged structure. Koskela (1999)

states that rework is carried out with minimum preparation and planning. This is often making a ravage to the sequencing of the work, and furthermore there is a risk that it would cause congestions and thereby slowing down or at worst completely stopping the production.

The fact that defects occur and that defects lead to waste implies that a reduction of defects would reduce waste and thereby increase productivity. Nevertheless, LPS is only focusing on the conduction of the schedule and trying to make the schedule itself more reliable. It is not focusing on the end product and not trying to enhance the quality in construction. Therefore, the only measure is the PPC. In worst case the production can be speeded up in order to archive high PPC, but then later witness lots of defects and poor quality, which again lead to waste consisting of waiting, motion, transportation and rework.

PPC is often used as a measure of the performance of the construction site. If quality is not taking into account it gives a disfigured picture of the performance. To restore the picture poor quality and related defects should be deducted from the performance. To secure a consistent judgment of quality the control could either be undertaken by the construction manager or by the crews which undertake the subsequent assignments. Here the minimum criteria for acceptance must be that current standards are followed and that the outcome is correct. If only acceptance is the criteria for quality, the amount of rework can be used as an indicator of quality.

6 Conclusion

This research is based on a case study of an offshore construction site in Denmark. In order to prove that defects and errors are common in construction, a short literature survey was conducted. This was done to compare existing theory with the new empirical knowledge. Through comparison it was found that the conducted research supports existing theory and state that errors and defects are common in construction and that the related cost and time consumption is significant.

Defects and errors in construction lead to an unpredictable and chaotic construction process. The case study revealed two possible ways to increase reliability, both related to LPS. The two aspects are related to LPS ability to respectively handle soundness and quality.

A central element in LPS is the making ready process, which secures that all preconditions are removed. When all preconditions are removed the assignment is moved to a workable backlog, from here the sound assignments are later moved to the Weekly Work plan. This case study shows that changes in preconditions take place. To detect changes and secure that only sound activities end up in the Weekly Work plans a weekly “health check” is proposed.

To secure a reliable and continuous improving scheduling the PPC measurement was introduced. In order to reduce the number of defects and errors, this research suggests that there should be a focus on the end product. Therefore, this research recommends that quality is implemented as a supplement to the PPC measurement.

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Scheduling of Large, Complex, and Constrained Construction Projects – An Exploration of LPS Application

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Abstract:

Scheduling of construction projects is by nature complex. The construction process is unreliable and difficult to forecast. Last Planner System (LPS) is introduced in construction in order to achieve greater reliability and productivity in the process. To ensure that implementation is successfully anchored in the organizations, differences between theory and application are investigated. To determine the theoretically correct application a literature survey is conducted. A questionnaire survey is made to collect empirical data of the practical application. Comparison between theory and application revealed that often only parts of LPS are applied. A partly applied LPS can be a main barrier to increased reliability in the scheduling process. Furthermore, the questionnaire showed that failures in the execution processes often start in the Lookahead Plan. Here, lacking knowledge of the execution process is causing problems to be overlooked. To increase the level of knowledge foremen should be involved in the Lookahead planning.

Keywords:

Last Planner System, reliable, implementation, application, scheduling

1 Introduction

Production conditions in construction are different than in the manufacturing industry. First of all, construction is rooted in place and conducted as on-site or fixed position manufacturing (Ballard 1998; Schmenner 1993). Here, the size of the construction entails that it is, opposite conventional manufacturing, the craftsmen who move through production instead of the product (Ballard 1998; Ballard 2000). Furthermore, every construction project is unique and often referred to as one-of-a-kind production. The construction process is managed by a temporary organization consisting of several companies. Moreover, the construction process itself is complex (Aritua, Smith and Bower 2009; Dubois and Gadde 2002; Ballard 1998; Bertelsen 2003a; Bertelsen and Koskela 2004; Salem et al. 2004; Salem et al. 2006).

Highly interdependent activities have to be conducted at limited space, with multiple components, a lack of standardization, and with many trades and subcontractors represented on site (Ahmad and An 2008; Ballard and Howell 1995; Bertelsen 2003b; Bertelsen and Koskela 2004). This interrelation results in a production where different contractors perform interacting and overlapping activities. This increases uncertainty and make the construction process very difficult to schedule (Bertelsen 2003b; Salem et al. 2006).

Additionally, a lot of unpredictable factors such as the weather can affect scheduling and make the construction even more complex (Bertelsen and Koskela 2004). Besides the complexity aspect, the construction process is also dynamic. If the construction layout is observed, it will change as the

construction progress. Work areas move, and material and crews vary based on the demands of the current activities (Choo and Tommelein 1999).

The temporal type of work complicates communication and standardization. Furthermore, subcontractors work on several projects, which lead to a competition for the subcontractors' resources (O'Brien 1998). This creates an invisible connection between several projects, thus turbulence can be easily transmitted from one project to another (Bertelsen 2004; Bertelsen and Koskela 2004). Additionally, every contractor is trying to optimize the utilization of his own resources. According to Hopp and Spearman (2000) this suboptimization gives rise to prolonged cycle time and growing buffers, which finally result in waiting time to the other contractors.

Combining these key characteristics results in uncertainty (Howell and Ballard 1997; Salem et al. 2006). Uncertainty reduces the reliability and thereby introduces variability into the construction process. Variability is critical to the production. Hence, it is a key to improvement in the construction industry.

The traditional view on construction production has been a transformational view. Construction has been understood as a conversion of input into output (Chua, Jun and Hwee 1999; Koskela 2000a; Koskela 2000b; Slack et al. 2000; Starr 1966).

Koskela (1992) criticizes the transformation model for neglecting the importance of flow and value. He states that by understanding production as conversions only, the physical flows consisting of moving, waiting and inspecting activities are missing. He continued by stressing that these activities are not adding value to the end customer (Koskela 1992).

In an attempt to make construction Lean, Koskela introduces the Transformation – Flow – Value (T-F-V) theory. It shares many common elements with Lean Production but different characteristics in assembly environments and processes entail that Lean Production does not fully fit into construction (Salem et al. 2006). However, Lean Construction still follows the idea from Lean Production to optimize production in the pursuit of perfection (Howell 1999). T-F-V sees the production as a flow of materials starting from raw materials and ending as the final product. The material flow is undergoing moving, waiting, inspection, and conversion before the construction is finished (Koskela 1992; 2000b).

The construction industry has only experienced limited performance improvement compared to the manufacturing industry (Bertelsen 2004). One of the reasons for focusing on performance is the great impact on macro economy. If the national GNP is considered, the construction sector in most countries accounts to approximately 10% of the GNP (Seaden and Manseau 2001). Therefore, even small improvements in the construction sector will have a noticeable impact on the GNP (Bertelsen 2004; Wandahl et al. 2011).

Through a field study Howel and Ballard find that only about half of the assignments in a traditional schedule are conducted as planned (Ballard 1999; Howell and Ballard 1995,). Ballard (1999) further find that half of the time is spent on value adding work. In an attempt to raise the level of planned activities completed Ballard begins to develop the Lean tool Last Planner System of Production Control (LPS). LPS is based on the mindset of Lean Construction. In Denmark Lean Construction and LPS is becoming popular. This interest has made many of the major contractors member of leanconstruction.dk a Danish sister organization to Lean Construction Institute.

Numerous studies indicate that implementation of LPS leads to an increased project performance. Furthermore, the studies report improvement in plan reliability, project delivery time, and labor

productivity (Alarcón et al. 2005; Alsehaimi, Tzortzopoulos and Koskela 2009; Ballard 1999; 2000; Formoso and Moura 2009; Friblick, Olsson and Reslow 2009; Garza, Leong and Walsh 2000).

When implementing theory one must be aware that anchoring the theory deep into the organization is critical. Even though, differences between developed and often complex theory and adopted practice are expected. Moreover differences between theory and actual application can develop over time. To secure no misuse of the system there must be a focus at the differences between intended and actual application. This research investigates the extent of differences between theory and application of LPS and looks into the adoption of LPS in Denmark, through the following research question:

How well is LPS adopted and applied in the Danish construction industry?

The remainder of the paper is structured as followed. First section 2 presents the research methodology of both the literature and the questionnaire survey. In section 3 the outcome of the literature survey is presented. Thus section 3 is containing the theoretical background to LPS and its application. In section 4 the results of the questionnaire survey is presented. The results are in section 5 followed by a discussion of the findings. Finally section 6 contains the conclusion.

2 Research Methodology

This research consists of two main elements: A systematic literature review of LPS, and a questionnaire survey. The purpose of reviewing LPS is to determine the theoretical foundation of LPS. At the same time the literature survey gathers information from the published research and shows how this field has developed throughout history. The questionnaire survey contributes with knowledge on how LPS is applied. Afterwards, theory is compared with practical application, and important implications that surfaces are discussed.

2.1 The literature survey

This research tries to investigate the Lean Construction approach to production with focus on LPS. Focus is on areas in theory to develop and improve. To get an insight in the Lean Construction theory a literature survey is performed by systematically including relevant publications. The methodological approach of the review takes its outset in the review strategy presented in Pittaway et al. (2004). The survey was limited to include publications dealing with the Toyota Production System, the T-F-V theory and LPS. However, literature both dealing with theoretical, conceptual and implementation aspects were included.

When looking at the cited literature 18 journals, 3 PhD theses, 29 conference papers, and 6 books were included in the survey. Journal articles were included in the survey and cited when found relevant. The reason for the high number of conference papers is that most publishing concerning LPS has taken place at the IGLC conference. This is in particular the case during the basic evolvement of the theory.

2.2 The questionnaire survey

To investigate the application of LPS an online questionnaire survey was conducted. The survey started the 11th of August 2011 and ended at the 21st of September 2011. The questionnaire was devised with outset in designing theory presented in (Forza 2002). The samples in this survey were A) the members of leanconstruction.dk, comprising 16 contractors representing the major contractors in Denmark. If possible to locate email address, the survey was distributed directly to the employees else a general mail was sent to the main office and from there distributed to the employees. B) The questionnaire was sent to former students at the MSc in construction management programme at Aalborg University working as contractors. In total 192 persons were included in the survey.

Through comparison of email addresses it is ensured that the same person does not receive more than one questionnaire. It is considered acceptable that the same firm contributes to the survey with multiple questionnaires.

The questionnaire was completed by: 14 project managers, 17 construction managers, 16 site managers, and 7 foremen with varying education and experience. Moreover 5 did complete the survey without stating their position. The selected participants cover the different levels of scheduling in a construction project. They represent varying opinions and contribute with different experience to scheduling. This secures an unbiased and valid survey.

The questionnaire process takes its outset in the strategy presented in (Akintoye and MacLeod 1997). The survey proceeded as follows. First, an initial invitation was sent out to every participant and after two weeks a reminder was sent out to those who had not yet completed the survey. In total 59 persons (19 former students now working as contractors, and 40 from enterprises) completed the survey resulting in a response rate of 31%. The response rate is thus above the critical response rate of 20 % (Malhotra and Grover 1998). The questionnaire is constructed of successive questions where respondents continuous are sorted and depending on the answers can be discarded. Therefore, the number of respondents will vary from question to question. No completed questionnaires have been rejected by the authors due to incorrect answers.

Since the survey covers the members of leanconstruction.dk and the educated civil engineers from the construction management programme at Aalborg University working as contractors. The participants are expected to know about and have experiences with LPS. This increases the quality of the replies and the validity of the survey.

Differences between intended and actual application of theory is important. The risk of insufficient or non-intended application is a general issue and should be treated with great awareness when designing or implementing theory. Therefore, the research is transferable and of great importance to general project management.

3 Literature review of LPS

The LPS approach can be divided into three main elements: Stabilizing workflow, improving downstream performance and reducing inflow variance. The first and crucial step is to stabilize the workflow. Stabilization of workflow is attained by shielding each process against variations from upstream activities. This being variations which management has not succeeded in eliminating, which would be the ultimate but idealistic goal. With the shield installed, it now becomes possible to handle problems both up- and downstream. Downstream, an increase in effectiveness and productivity can be gained. Upstream, the inflow variance can be reduced (Ballard 1994; Ballard and Howell 1994).

3.1 Stabilizing workflow

Stabilization is a prerequisite for improvement, by stabilizing workflow a substantial reduction in both project duration and costs can be gained (Ballard and Howell 1994). Furthermore, stabilization of the workflow increases the reliability of the workflow which according to Ballard and Howell (1994; 1995) improves the interrelations and makes it easier to match resources and capacity and moreover, it improves productivity. The correlation between increased reliability and productivity is supported by a case study conducted by Liu and Ballard (2008).

The stabilization of workflow starts with realistic plans and schedules, which can be observed. In construction, there are many levels of planning. Ballard (1994, p.108) defines the last planner, as the

planner whose output is “*not a directive for a lower level planning process, but results in production.*” This is understood as “*commitment planning*” which is carried out in the Weekly Work Plans, because it is here activities, which WILL be done are selected (Ballard 1997; Ballard and Howell 1994; 1998).

The last planner has the responsibility of making schedules, which contain what WILL be executed. This has to ensure that activities that SHOULD be conducted are done to the extent that it CAN be done. To perfect the planning process the plans (WILL) are compared with what DID take place. From this important learning on differences and root causes can be detected and eliminated to reduce variations and prevent repetitions (Ballard 1994; Howell and Ballard 1994).

The earlier mentioned shielding occurs when the last planner is selecting only tasks that (s)he knows can be completed. One way to do this is to create a workable backlog of activities, which are ensured, can be performed. This backlog serves also as a buffer against variations and unforeseen events and secures that production is on track (Ballard 1994; Howell and Ballard 1994).

An approach for achieving a reliable planning is to ensure that all constraints are removed this ensures that the planned activities can be carried out; another approach is to select what should be. The last planner has to select the right amount of work and simultaneously secure that the work is conducted in the right sequence. The right amount, or size, of work is enough work to utilize the present capacity of labor and equipment. This maximizes throughput and ensures that the construction project can finish on time. To achieve high utilization the selected assignments need to be specific and defined in detail. The right sequence is the sequence which, under the given conditions, secures that the connected activities are conducted in an optimal order with focus on the end product. Thus, it is essential that planning is conducted independently and across work scopes, in this way interdependencies are discovered (Ballard and Howell 2003). According to Bennett (1985) interdependencies and productivity across work crews has been one of the major obstacles in the attempt to achieve production control. Because of a general increase in complexity these interdependencies have together with workflow increased uncertainty (Jang and Kim 2008).

The shielding process includes aspects, such as soundness, sizing, sequencing, and definition; and forms together with learning the quality criteria of assignments (Ballard 1999; Ballard and Howell 1998; Jang and Kim 2008). Where learning is the ability to identify reasons for non-completion to interfere and, thereby, avoid repetitions (Ballard 1994; Ballard and Howell 1998).

WILL should be compared with DID to ensure that the project is on track and to reveal problems and thereby determine where to intervene. According to LPS “*the starting point for improvement in planning is measuring the percentage of planned activities completed PPC, identifying reasons for non-completion, and tracing reasons back to root causes that can be eliminated to prevent repetitions*” (Ballard 1994, p.111). This is also supported by Filho and Soibelman et al. (2004) and by Rozenes and Vitner (2010, p.40) who state that “*project performance can be improved if more attention is given to the issue control*”. LPS introduces the PPC measurement to be able to distinguish between quality failures and failures to execute conducted plans (Ballard 1994; Ballard and Howell 1994).

The PPC measurement increases commitment to learning, which reduces waste such as non-productive time, which improves the possibility to meet expectations and again releases time and energy to further improvement in performance (Ballard 1994). Furthermore, learning from mistakes can enhance a construction company’s competitiveness in the surrounding market (Arditi, Polat and Akin 2010).

3.2 Reducing inflow variation

Variations occur everywhere in construction; variations in delivery, work pace, etc. occur. Both positive and negative variation is undesirable. Positive variation can result in tied-up capital or rehandling of materials (Ballard and Howell 1994). Negative variation is destructive to plans and schedules, and is causing delays (Howell and Ballard 1994).

An approach to limit the effects of variation is buffers between activities. This minimizes the interdependencies and, thereby, the effect of variation. It insures that variation in upstream assignments does not affect downstream performance. Buffers are applied to keep production going without interruptions, i.e. a constant flow. According to Howell and Ballard (1994, p.97) buffering serves three key functions:

1. *Compensates for differing average rates of supply and use between the two activities.*
2. *Compensates for uncertainty in the actual rates of supply and use.*
3. *Allows differing work sequences by supplier and using activity.*

The negative side of buffering is the cost. Buffering is an expensive solution to handle variations (Ballard and Howell 1995; Howell and Ballard 1994). Costs associated with buffering involve idle inventory, buffer fill time, loss prevention, inventory management, double handling, and storage space. Therefore, the buffer size needs to fit actual demands, which can be difficult when supply and use rates are unknown and varying (Howell and Ballard 1994). It is important to note that by reducing uncertainty the reliability of the construction process will increase (Ballard 1999). This declines the needs for buffering, and the size of the required backlog (Ballard and Howell 1994).

3.3 Improving downstream performance

Downstream performance is a focal point when improving operation within the context of managed flows. Improving of operations downstream is looking behind the shield, beyond the commitments in the WILL-do plans. Planning is not limited to a selection of what WILL be done, as in the Weekly Work Plans. Daily plans and work methods are produced while production proceeds unaffected (Ballard and Howell 1994; Howell, Laufer and Ballard 1993).

This underlying planning, which goes beyond the Weekly Work Plan, is conducted by the foremen, subcrew and the individual craftsmen concurrently as production proceeds. A major problem in reaching better planning is to change the mentality of the foremen or craftsmen to say “can-do” even to poor assignments (Howell and Ballard 1997; Ballard 1999). By changing this mentality and moving beyond “can do” a more rapid learning process is achieved, which results in better planning (Senge et al. 1994). Every foreman conducting the underlying planning has an individual approach to both planning and control. One approach could be to control against standards based on experience, drawn from similar work (Ballard and Howell 1994).

3.3.1 Utilization of capacity

The characteristics, such as uncontrolled conditions and the uniqueness of construction, are the reason why “*variation is a fact of engineering and construction life*” (Ballard 1999, p.282). This basic variability is unavoidable, and is by Hopp and Spearman (2000) called the randomness of construction.

This randomness of construction is important when matching activities with capacity. By loading capacity at 100% the likeliness of assignments completed on time will decrease. According to Ballard (1999, p.282), it is “*better to underload production units in order to allow for variability in production.*” Underloading capacity induces unutilized capacity, but the build in backlog absorbs this unutilized capacity bringing the productivity up. Furthermore, underloading capacity increases

the reliability of upstream activities and improves the workflow; this benefits the downstream operations which will increase productivity (Ballard 1999).

3.4 A practical approach to the planning process

The LPS planning system consists of a long-term (Master Plan, Phase Scheduling), intermediate-term (Lookahead Plan), and short-term planning (Weekly Work Plan). This is consistent with Hoop and Spearman's (2000) three basic levels of planning: a strategic, tactic, and control level.

3.4.1 Long-term planning: Initial planning / Master Schedule

The initial planning points out what SHOULD be done (Howell and Ballard 1994). LPS did not make any changes in this level of planning. Traditionally a Master Schedule contains the overall activities and milestones, and serves as guidance for the lower level of planning (Ballard 2000).

The initial schedule contains several uncertain parameters. These are caused by the unpredictable nature of the construction process. Traditionally, this uncertainty is handled by updating the plans to reflect the current status and by forcing the production to run as planned (Howell and Ballard 1994). According to Tommelein (1998), the tendency to rigorously adhere to the initial schedule is the wrong approach. Tommelein (1998, p.281) argues that *"network characteristics and resource availability will deviate from those assumed when the schedule was generated."* She concludes that planning must be *"dealt with in real time"*. This is why uncertainty decreases the closer in real time the plan is to execution.

3.4.2 Long-term planning: Phase scheduling

One crucial and difficult task in construction is the sequencing of activities (Echeverry, Ibbs and Kim 1991). In an attempt to achieve a good sequence of activities LPS introduced Phase scheduling (Ballard 2000). The approach is to divide the project into main phases. To every phase milestones in form of completion dates are afterwards specified and by working backwards handoffs between crews or organizations are identified, and the sequence is determined (Ballard and Howell 2003; Hamzeh, Ballard and Tommelein 2008). Phase scheduling is thus a pull-driven scheduling technique (Vishal et al. 2010).

Phase scheduling coordinates activities and actions which extend beyond the window of the Lookahead Plan and structures the work of flow (Ballard 2000 and Howell 1999). Ballard and Howell (2003, p.2) further stress the importance of Phase scheduling by stating *"Phase Scheduling is the link between work structuring and production control. Without it, there is no assurance that the right work is being made ready and executed at the right time to achieve project objectives."*

Activities in the sequence can be divided into flexible and inflexible assignments. While the inflexible activities are fixed in the sequence, the flexible activities can to some extent be moved. Factors affecting the sequence are the physical relationship between construction components, trade interactions, path interference, and code regulations, see e.g. Echeverry and Ibbs (1991).

When making a phase's sequence it is important that every company involved in the construction project is represented and provides input, especially to activities which are interdependent (Howell 1999). According to Ballard and Howell (1994), the importance of participation is related to the improvement of the quality of the plan and not to increasing motivation (Ballard and Howell 1994).

Often, the sequence is made by letting the companies involved order their activities on PostIt notes. It is important to include relations and connections to both previous and following activities. These

notes are afterwards put onto a wall and collaborative structured to achieve the best sequence (Ballard 2000; Ballard and Howell 2003).

3.4.3 Intermediate-term planning: Look-ahead planning

To help the last planners in matching WILL with DID LPS has introduced a new type of planning, which is called a Lookahead process (Ballard 2000). This Lookahead process is a kind of making-ready-process where the activities planned in the overall schedule are made sound. In this process, constraints to each assignment are identified and removed (Jang and Kim 2008).

According to the LPS theory the soundness of an assignment depends on seven preconditions (Koskela 1999). If one of the preconditions is not fulfilled the assignment cannot be conducted. From this uncertainty and variations in the workflow will follow, leading to a high level of non-conformances and demotivated workers (Ballard 1994). The preconditions are related to construction design, materials, workers, equipment, space, connecting works, and external conditions respectively (Koskela 1999).

In the intermediate-term (Lookahead) planning, tasks and demands in the long-term planning are translated into “*a general plan of action that will help the site prepare for upcoming production*” (Kemmer et al. 2007, p.511).

Hoop and Spearman (2000) point out that through the intermediate-term planning the demands of the customer are translated into a set of actions; which will help in the preparation of the upcoming production. The Lookahead process is using a pull technique, where manpower, machinery, material, etc. are pulled to the construction site Just-In-Time. This ensures that the right crew, machinery, material, etc. is ready for the assignments (Chua, Jun and Hwee 1999; Tommelein 1998; Vishal et al. 2010).

The Lookahed Plan has several objectives, besides the sounding aspect. The primary is to shape the workflow in the best achievable sequence, match the workflow to capacity, reduce variability to stabilize the workflow, maintain a backlog of sound activities, split activities to assignments, and to discover interdependencies (Chua, Jun and Hwee 1999; Ballard 1997; 2000).

The Lookahead Plan links the Master Schedule to the Weekly Work Plans (Chua, Jun and Hwee 1999; Kemmer et al. 2007). The planning is conducted as a drop-out from the Master Schedule, with a span between 3-12 weeks. Each week slides the planning window one week forward (Ballard 2000). The size of the span is depending on project characteristics, the reliability of the planning, and the necessary duration of the sounding process (Ballard 2000).

When sliding the planning window forward only activities which can be made ready on schedule slides forward. When every precondition is removed the activities are moved to a buffer to maintain a backlog of assignments which can be performed. When conducting the Weekly Work Plans only assignments from the backlog are selected. This secures that only sound activities are moved to the Weekly Work Plans (Ballard 2000; Howell and Ballard 1994; Hamzeh, Ballard and Tommelein 2008; Steyn 2001). LPS suggests that the backlog should be kept at minimum two weeks. This ensures that enough sound activities can be moved to the Weekly Work Plans and thereby match the capacity and to buffer against unexpected constraints in the sound activities (Ballard 1997; 2000).

By securing that only sound activities are selected to the Weekly Work Plan the success rate of completed tasks is increasing, which thus entails that the uncertainty of the schedule is significantly reduced (Ballard 1997; Ballard and Howell 1994; Jang and Kim 2008). This increases certainty and honesty in the construction process, where “*we do what we say we are going to do*” (Ballard 1994, p.112). Furthermore, a reduced uncertainty in the schedule leads to reduced project duration and

costs (Ballard 1997). This claim is strongly supported by several studies, among others by a case study conducted by Tommelein (1998) which shows a significant time reduction when applying Lookahead planning.

3.4.4 Short-term planning: Commitment planning / Weekly Work Plans

The final level is the Weekly Work Plan (Ballard 2000). Here, commitments are made, and it is decided which activities are to be conducted and when. When selecting which activities WILL take place, only sound activities from the Lookahead Plan are selected.

LPS did not change the traditional Weekly Work Plans, but implements a feedback system, called the PPU measurement (Ballard 2000). As mentioned before, WILL is through the PPU compared with DID, where the quality of the Weekly Work Plan is measured. This comparison will normally take place at a weekly basis. If a given activity is not completed as planned, reasons are identified and root causes are afterwards eliminated. The PPU serves thus both as a feedback and learning system. By learning from failure improvements can be archived, which results in increased productivity or savings.

4 Application of LPS

One thing is theory and the intended use of the Lean tool LPS, another is the practical application of the system by practitioners. To detect differences between theory and application, a questionnaire was designed. First of all, the questionnaire showed a general lack of knowledge of Lean Construction. When asked “*how does Lean Construction see production*” 78,1 % did not think transformation, 28,1% did not think value creation, and 18,8% did not think flow as a part of the Lean Construction view of production.

The LPS approach consists of a set of elements, which together ensure a reliable schedule. The questionnaire revealed that LPS is not applied as a complete system. Instead only parts of LPS are applied. Combined with the general lack of knowledge this is considered to be one of the barriers towards a more reliable schedule. The results of the question “*which elements of LPS have you applied*” can be seen in Table 1. Especially learning and pulling is rarely applied.

Table 1 “Which elements of LPS have you applied?”

	Respondents (n=)	Percent (n/N·100=)
Weekly Work Plans	34	91,9%
Lookahead Plan	32	86,5%
Phase Schedule	31	83,8%
Master Schedule	30	81,1%
The seven preconditions	25	67,6%
Sequencing (PostIt)	20	54,1%
PPC	18	48,6%
Pulling (Just In Time delivery of materials)	14	37,8%
Buffering	12	32,4%
Learning (PPC)	11	29,7%
Total (N=)	37	100,0%

The tendency to modify LPS was confirmed when asking if all elements of LPS have to be applied. The results can be seen in Table 2.

Table 2 “Does all elements of LPS always have to be applied?”

	Respondents (n=)	Percent (n/N·100=)
To a very high degree	3	8,1%
To a high degree	1	2,7%
To some degree	14	37,8%
To a lesser degree	4	10,8%
Not at all	13	35,1%
Don’t know	2	5,4%
Total (N=)	37	100,0%

In Table 1 the tried out elements of LPS are presented. Currently applied elements of LPS are presented in Table 3. Some of the respondents had relation to more than one construction project. Therefore, the total number of construction projects exceed the number of respondents. This gives an updated picture of which elements currently are applied and anchored in the organizations. Here, differences in the apply frequency is clear and apparent. Some elements such as Master Schedule, Lookahead Plan, and Weekly Work Plans are nearly always applied. Other elements such as PPC, learning, sequencing, and pulling are rarely applied.

Table 3 “Which elements are applied at current construction projects?”

	Construction projects (n=)	Percent (n/N·100=)
Weekly Work Plans	43	63,2%
Lookahead Plan	45	66,2%
Phase Schedule	37	54,4%
Master Schedule	51	75,0%
The seven preconditions	28	41,2%
Sequencing (PostIt)	22	32,4%
PPC	21	30,9%
Pulling (Just In Time delivery of materials)	17	25,0%
Buffering	20	29,4%
Learning (PPC)	16	23,5%
Last Planner not applied	12	17,6%
Total (N=)	68	100,0%

Respondents are selected from a sample where application or at least knowledge about LPS is anticipated. Only 63,8% of the respondents have heard about LPS, and of them only 72,7% have applied LPS to a construction project. From this it can be concluded that implementation of LPS has not fully occurred. Only very few companies do actually apply LPS, this can have affected the response rate of the questionnaire.

Another relevant finding is that 50% of the participating foremen have conducted time scheduling, and only 25% had used LPS. This indicates that the foremen are not included in the planning processes as intended. According to the LPS theory, the Weekly Work Plans are made in corporation with the foremen in order to increase the quality of the plan.

The Lookahead Plan should ensure that only sound activities are moved into the Weekly Work Plan. However, unsound activities occur in construction. To examine why this happens the respondents

were asked if failure in the making-ready-process was caused by lack of knowledge about the execution process, see Table 4.

Table 4 “Is failure in the making-ready-process caused by lack of knowledge about the execution process?”

	Respondents (n=)	Percent (n/N·100=)
To a very high degree	4	11,4%
To a high degree	16	45,7%
To some degree	4	11,4%
To a lesser degree	4	11,4%
Not at all	3	8,6%
Don't know	4	11,4%
Total (N=)	35	100,0%

To link the missing knowledge to the making-ready-process the respondents were asked if the missing knowledge to the execution process could be one of the reasons to why these problems are overlooked in the Lookahead Plan. This can be seen in Table 5.

Table 5 “Is lacking knowledge causing problems to be overlooked in the Lookahead Plan?”

	Respondents (n=)	Percent (n/N·100=)
To a very high degree	4	11,4%
To a high degree	21	60,0%
To some degree	8	22,9%
To a lesser degree	0	0,0%
Not at all	0	0,0%
Don't know	2	5,7%
Total (N=)	35	100,0%

5 Discussion

Analysis of the questionnaire shows that elements of LPS are omitted. Furthermore, analysis reveals a tendency to use only the overall planning system, including the Master, Lookahead and Weekly Work Plans. From this follows that optimizing and feedback instruments such as PPC measurement, making-ready by using the seven preconditions, buffering, Phase scheduling, and Just-In-Time delivery often are ignored.

The PPC measurement was introduced as a feedback system to reveal problems, and thereby keep the project on track. Without the PPC measurement, problems is discovered too late, they would have more time to evolve, and thus have greater negative impact. It is important to learn from mistakes, according to LPS, root causes to non-completion shall be identified and eliminated. By not eliminating the root causes future repetitions are not prevented and no long lasting improvement is achieved. From this follows that the chance to increase reliability of the schedule is not exploited.

The seven preconditions serve as a making-ready instrument in the Lookahead Plan. It is a key element in the sounding process. If not applied, variation will increase leading to an unreliable scheduling and a changing workflow. Buffering of sound work tasks functions as a shield against variations and minimizes the effect of interdependencies. No buffer will result in varying workflow surfacing as non-productive time.

If Phase scheduling and the connected PostIt method is not applied, the optimal sequence of the workflow is not found. This results in a situation where the different sub-contractors make no consideration to assignments with interdependencies. In construction where the workers move through production, interdependencies are particularly important.

Each element in the LPS serves a purpose. If one element is not applied the associate function in the LPS is missing. Therefore, it is essential that the system is fully understood when application is done only partly or adjusted. Else it can be very costly.

Maybe all elements do not require a formal system, but as a minimum requirement it must be incorporated and regarded during the construction project. If an element is intentionally deselected it has to be replaced by a similar element. Still, it has to be stated that it is critical that site managers without proper knowledge about LPS adjust the system to fit a specific construction project. It is important to stress that limited knowledge about LPS could have affected the answers. This occurs if the participants do not know or recognize the elements applied in practice.

This research was limited to look at the application of the different elements of LPS in practice. The actual use of the applied tools was neither regarded nor compared to theory. The lacking knowledge of LPS could imply that daily use of the elements in LPS also is differing from theory. An incorrect use of LPS would cause a decrease in productivity at the construction site.

The study also revealed that missing knowledge of the execution process could be one of many reason to why problems are overlooked in the Lookahead Plan. Other reasons could be the complexity of the projects, limited time, or limited focus and understanding of the importance of the planning process. Overlooked problems are strongly related to failure in the execution process. Lack of knowledge can of course be caused by many parameters, one of them being not involving foremen. Thus the missing involvement of foremen in the planning process can explain why failure arose in the making-ready process.

From this it can be concluded that in order to increase the quality and thereby the reliability of the planning process, foremen should be included in the Lookahead planning. This could be a key to increasing the general PPC level.

6 Conclusion

To explore the theoretical basis of LPS a literature survey was conducted. Here, both the theoretical background and the proposed application were examined. Furthermore, a questionnaire survey dealing with the application of LPS was conducted and comparisons between theory and practice were made. Through comparison gaps between theoretical and practical application of LPS were found. An interesting finding was a general lack of knowledge to LPS.

To answer the research question stated in the introduction part, the practical application of LPS was examined. This revealed that often only parts of LPS are applied. LPS is often limited to include only the overall planning system, including the Master, Lookahead and Weekly Work Plans. Each element in the LPS serves a purpose. If one element is not applied a small part of LPS is missing. Therefore, knowledge of LPS is extremely important when adjusting the system. This research states that limited knowledge of LPS is one main barrier to increased reliability of the schedule.

Another interesting finding from the questionnaire was that the root to failure in the execution processes already starts in the Lookahead Plan, where problems are overlooked. This could among others be caused by lack of knowledge. Therefore, one approach to increasing the quality of the plan

could be to increase the use of foremen. They have practical knowledge and are able to predict potential problems. Therefore, this research recommends that foremen are involved in the Lookahead planning. In future research the data set will be expanded to enable comparison of the different sub-groups. This will reveal different pattern in application of LPS in relation to for instance their position. Furthermore case-studies will be conducted. Here current use of the individual elements in LPS will be compared to the theoretical approach.

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Exploration of Correct LPS Practices in Scheduling of Large, Complex, and Constrained Construction Projects

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Abstract:

Last Planner System (LPS) is introduced in construction to make the sites Lean. LPS has been facing implementation challenges which result in a misused or limited LPS. To compare application with theory, daily application of LPS was monitored at three construction cases. In all cases it was registered that only parts of LPS were applied. When application was compared with theory it was found that some elements were misused. The four main schedules were all applied, but the interactions between the plans did not function. Moreover, the rules of the making-ready process were not observed, and were offered little concern. The result was a low-efficient scheduling tool. To overcome the implementation challenges of LPS the knowledge level first needs to be increased. Furthermore, there is a need for support in the entire organization. More energy or stubbornness should be put into the implementation to anchor the changes deep into the organization.

Keywords:

Last Planner System, Scheduling, Application, Implementation, Lean Construction

Biographical Notes: Søren Lindhard is a Ph.D., student in Construction Management at Aalborg University where his topic is scheduling at construction sites. Here he is doing research related to the Lean scheduling tool, Last Planner System. With focus on Lean Construction Søren both supervises and teaches master students at the Construction Management programme at Aalborg University. Furthermore, his focus and interest for Lean Construction and specifically Last Planner System is clear in his scientific contribution.

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1 Introduction

Last Planner System (LPS) is implemented as a scheduling method at construction sites in an attempt to make the production Lean and thereby increase productivity. LPS is based on Lean thoughts and is developed to improve the scheduling processes to remove variability. Variability is decreasing productivity (Rooke *et al.* 2007; Koskela 2004; Thomas *et al.* 2003). The relationship between variability and productivity is demonstrated in the "Parade of Trades"

simulation by Tommelein et al. (1999). By removing variability the workflow is stabilized (Ballard 2000). A stable workflow leads to increased reliability of the schedule which most likely results in increased productivity (Liu and Ballard 2008).

The foundation of LPS consists of four main schedules. 1) The Phase Schedule, 2) The Master Schedule, 3) The Look-ahead Plan, 4) The Weekly Work Plans (Lindhard and Wandahl 2012; Ballard 2000; Cho and Ballard 2011).

Transition from traditional time scheduling to LPS has increased the number of planned activities completed (PPC). Before LPS was introduced, the PPC level was approximately 50 %, and after implementation the PPC raised to around 70 % (Ballard 2000; Ballard and Howell 1998; Ballard 1997). Furthermore, a decrease in non-productive time from 50 % to 35 % is disclosed (Ballard 1999). Non-productive time only includes the loss of productivity which can be assigned to delays and rework.

In today's construction industry, lean construction and LPS have gained a wider acceptance (Cho and Ballard 2011; Höök and Stehn 2008). Therefore, correct implementation of LPS is a challenge which is essential for securing an efficient planning and conduction of construction tasks. Research has shown that implementation of construction management theory in general is facing several challenges to secure a well implemented and well anchored theory. This is also the case with LPS.

Through a literature survey Vishal *et al.* (2010) find 12 different challenges to the implementation of LPS. They divide the challenges into two main categories: Challenges faced during the implementation phase, and challenges faced during the use of LPS. The 12 challenges are listed below (Vishal *et al.* 2010).

Implementation challenges

1. Lack of training
2. Lack of leadership/failure of management commitment/organizational climate
3. Organizational inertia & resistance to change
4. Stakeholder support
5. Contracting and legal issues/contractual structure
6. Partial implementation of LPS & late implementation of LPS

Use challenges

7. Human capital & lack of understanding of the new system; difficulty making quality assignments/human capital–skills and experience
8. Lack of commitment to use LPS & attitude toward the new system
9. Bad team chemistry & lack of collaboration
10. Empowerment of field management/lengthy approval procedure from client and top management
11. Extra resources/more paper work/extra staff/more meetings/more participants/ time
12. Physical integration

These challenges limit the effect of LPS and result in a low efficient scheduling tool. Thereby, the potential improvements in both scheduling reliability and productivity are lost. All 12 challenges have to be dealt with to secure a well implemented LPS. If just one challenge is overlooked it will surface as a partly implemented, limited, or misused LPS.

Recently research has uncovered implementation problems with LPS. In a research study conducted by Lindhard and Wandahl (2012), it is registered that implementation of LPS often is limited to involve only parts of LPS. From the findings Lindhard and Wandahl (2012, p.12) state: *“Each element in the LPS serves a purpose. If one element is not applied the associate function in the LPS is missing.”* The result is a low efficient scheduling tool, and lower productivity. The previous research did not show if these applied elements were implemented correctly. This will reveal the extent of the problem and help increase the appreciation. A complete appreciation of the problem is important when attempting to look behind the surface to see the unsolved challenges. Furthermore, implementation issues are important in order to achieve continuous improvement. Continuous improvement (Kaizen) is an essentially part of the lean philosophy and vital in the search for excellence in the construction industry.

The risk of insufficient or non-intended implementation or application of theory is an issue which is relevant and of great importance to project managers and researchers in general. Therefore, it should be treated with great awareness especially when designing or implementing theory. Consequently this issue is examined through the research question:

How does on-site usage of the elements in LPS correspond to theory?

2 Research Methodology

Three construction cases were followed to observe how the elements of LPS were applied in practice. The research focus was important. Without a research focus it is easy to get overwhelmed by the volume of data (Eisenhardt 1989). Eisenhardt's opinion is shared by Mintzberg (1979, p. 585) who states *“No matter how small our sample or what our interest, we have always tried to go into organizations with a well-defined focus - to collect specific kinds of data systematically.”* Therefore, the objective of the case-studies was clarified beforehand. Relevant sources of data were considered and need-to-know data was determined.

The research was conducted as a qualitative research where archives, observations, and interviews were used to collect data from the cases. The qualitative approach was chosen to view the problem in its context. Only in its context the actual application of LPS can be examined. This is supported by both Eisenhardt (1989) and Yin (2003) who state that how and why questions only can be answered with qualitative research. The context is important, because it can affect behavior and process. Furthermore, the context is influenced by the selected behavior and process (Hartley 2004).

The case-study takes its outset in guidelines presented in Eisenhardt (1989). The case-studies were conducted with an explorative approach where application of LPS was tested. Eisenhardt (1989) recommends that the number of cases is determined by when a *“theoretical saturation”* is reached. According to Romano (1989) it is the individual researcher's choice to determine the number of cases. Three construction cases in the execution phase were selected. The three cases were considered satisfying, due to the amount of data from each case. Furthermore, the results later on show consensus.

To select the cases phone conversations and mail correspondences with company consultants and site managers were used. This secured that LPS was implemented. Furthermore, the contractor had as a minimum to be a prime contractor with associating subcontractors. In all cases the contractor turned out to be a member of leanconstruction.dk¹. The association comprises 16 contractors applying Lean Construction, which represents a large proportion of

¹ Danish sister organization of Lean Construction Institute.

contractors in Denmark. These selection criteria were added to increase the validity of the research. Data collection from the three cases is listed in Table 1 which is followed by a short case description.

Table 1 Data collection at the three case-studies

	Case 1	Case 2	Case 3
Contract form	Turnkey contractor	Turnkey contractor	Prime contractor
Site observations	Once every fortnight in total 5 observations.	1-2 times every fortnight in total 8 observations.	1-3 times every fortnight in total 8 observations
Meetings participated in	Subcontractor, foremen and safety meetings	Subcontractor and LPS meetings	Subcontractor, foremen, emergency and construction meetings
Observation length	10 weeks	10 weeks	10 weeks
Interviews of site-manager	Unstructured and semi-structured	Unstructured and semi-structured	Unstructured and semi-structured
From archives	Reports from meetings, various schedules and organisation charts	Reports from meetings and various schedules	Reports from meetings and various schedules

2.1 Case one – Housing

Case one was a renovation project of 16 three-storey residential apartment blocks containing a total of 309 flats. The blocks were dispersed between 5 blocks containing 15 flats, 11 blocks containing 21 flats, and additionally 3 handicap or senior houses. The project included rehousing of the residents. Rehousing was limited to a period of the length of 7 weeks. This was followed by a period of one week's length where the residents could compose a discrepancy list, and finally a one week's period for repairing the deficiencies. The project contract value was \$4.45 million, with a duration fixed on 26 months.

2.2 Case two – Educational institution

Case two was the construction of an educational institution. In total 6 different university educations were later on located in the buildings. The project consisted of two buildings in total 11000 m². The main building was a three-storey building plus basement, in total 8000 m² and had an autonomous contract value on \$21.75 million. The secondary building was a two-storey building with no basement, in total 3000 m². In total the secondary building had an autonomous contract value on \$7.36 million. The project was prestigious and modern and had to meet the highest standards within sound, fire, ventilation, intelligent control, etc. Simultaneously the construction period was restricted to 16 months. Therefore, as a turnkey contractor, the primary focus was on keeping the production flows running.

2.3 Case three – Nursing home

Case three was construction of a nursing home. The project consisted of 6 one-storey apartment blocks in a nursing home. In total 68 flats. The blocks were dispersed between 2 blocks with 10 flats and 4 blocks with 12 flats. Additionally the project included the construction of 4 common houses. The contractor worked as a prime contractor and had the primary responsibility with concrete, soil, sewer, concrete elements, steel, and weather covering. The project contract value was \$3.89 million, with a contract period of 17 months.

3 An introduction to LPS

As earlier mentioned LPS consists of four main schedules. The theoretically correct application of these schedules will briefly be presented in the following.

1) Phase scheduling focuses on the sequencing of activities. The aim is to secure a logical and good sequence which leads to a good workflow at the site. Activities in the sequence can be divided into inflexible and flexible assignments. Here, the inflexible activities are fixed in the sequence, while the flexible activities can be moved (Echeverry *et al.* 1991). Phase scheduling is a long-term scheduling tool, which looks at problems for the construction project as a whole, but it has a focus on the individual phases which the project goes through (Ballard 2000; Howell 1999).

The approach when conducting Phase scheduling is first to divide the construction project into main phases. Afterwards milestones and completion dates are specified on phase level. By working backwards from these deadlines handoffs between crews and organizations can be identified. Based on these the sequence is determined (Ballard and Howell 2003; Hamzeh *et al.* 2008).

In practice the contractors involved arranged their activities on Post-It notes. These notes were put onto a wall and collaboratively structured to achieve an efficient sequence. Interdependencies needed to be included. Therefore, across trades focus needs to be on relations and connections between both previous and following activities (Ballard 2000; Ballard and Howell 2003). When conducting the Phase schedule, it is important that every contractor involved in the project is represented, and provides input to the schedule (Howell 1999). Participation is important because it improves the quality of the schedule (Ballard and Howell 1994).

2) The Master Schedule contains milestones and main activities, and serves as guidance for the lower level of planning. The order of the milestones and especially the activities is based on the sequence decided during the Phase scheduling process. The Master Schedule contains several uncertain parameters and needs to be updated as the project progresses. Since the construction site is dynamic the predefined conditions which compose the basis of the plan change. Therefore, it is important that the overall plan continually is rethought (Howell and Ballard 1994; Tommelein 1998).

3) The Look-ahead schedule is introduced as a link between the Master Schedule and the actual work plans (Chua *et al.* 1999; Kemmer *et al.* 2007). The schedule is a dropout from the Master Schedule containing a span between 3-12 weeks. As the project progresses the schedule is sliding forward. The size of the span depends on the necessary duration of the making ready process, the reliability of the plans, and project characteristics such as complexity (Ballard 2000).

The Look-ahead schedule increases the reliability of the schedule because it contains a making ready mechanism where activities are made ready for conduction. During the making ready process, constraints to each activity are identified and removed before the activity is sound (Jang and Kim 2008). In LPS theory seven different preconditions have to be fulfilled before an activity is ready for conduction. The preconditions are related to construction design, materials, workers, equipment, space, connecting works, and external conditions (Koskela 1999).

To secure fulfillment of the preconditions, materials are pulled to the construction site when needed. This Just-In-Time delivery of materials minimizes the need for stock and the chance of dwindling materials, which is important both when production is carried out with limited space.

When an activity is sound, it is moved to a buffer in an attempt to keep a backlog of activities ready for completion. Only activities from the backlog can later be selected when completing the Weekly Work plans. In this process workflow is matched with capacity. This secures that only sound activities are moved into the schedule (Ballard 2000; Hamzeh *et al.* 2008; Howell and Ballard 1994; Steyn 2001). The backlog also serves as a shield against variations and unexpected constraints in the sound activities (Ballard 1997; Ballard 2000).

4) The Weekly Work Plan is where binding commitments are made (Ballard and Howell 1998). Since the Weekly Work Plan is the lowest level of scheduling the output from the plan results in production (Ballard 2000). When making commitments it is important that only sound activities from the backlog are selected.

To measure the quality of the scheduling, LPS uses the PPC measurement. Here, the level of non-completed tasks is calculated. Afterwards the reasons for non-completions should be identified and the root causes eliminated, cf. the seven preconditions. The PPC measurement serves thus both as a feedback and as a learning system. Learning from failure will result in improvements in reliability and moreover which increase productivity. Furthermore, learning from mistakes can enhance a construction company's competitiveness in the surrounding market (Arditi *et al.* 2010).

4 Results

In the following sections the scheduling approach for the three cases is shortly presented. Here, the primary focus is on application and daily usage of elements in LPS. In every case the description is divided into four groups in relation to the four main schedules presented earlier.

4.1 Case one – Housing

1) To secure a good sequence a kick-off meeting was held. Here, Phase Scheduling was conducted by applying the PostIt method. The sequencing did involve all contractors, who collaboratively found the sequence. The process did correspond to theory; however, a cyclogram was used instead of a classical network diagram.

2) The sequence found during Phase Scheduling formed the foundation of the Master Plan. Because of several repetitions the site-manager decided to draw the Master Plan as a cyclogram. Later the diagram was supplemented with a traditional Gant-map to ease the reading for the craftsmen. When necessary the schedule was rethought, but only the cyclogram was updated. Even though the project was significantly delayed, the site-manager chose not to update the Gant-map. Project delay was in that connection not regarded as a necessary reason for updating the plans. Instead he used the Master Plan as a management tool which indicated whether the project was on schedule or not.

3) Every Tuesday a sub-contractors meeting was held. In outline the meeting concerned regulations for the construction site, time scheduling, manning, downtime, and it ended with comments to the individual contractor.

The Look-ahead plans were conducted with a 5 week span. The Look-ahead plan was completed by the site-manager and drawn as a cyclogram. The plan was sent to the contract

managers shortly before the subcontractor meeting was held. The Look-ahead plan was briefly reviewed at these meetings. Here, the subcontractor's had an opportunity to comment the plan. It was afterwards the individual contractor's own responsibility to secure that their activities were made sound. At the meeting no focus was on the making ready process, on the seven preconditions, and on keeping a buffer of sound activities. Material deliveries were scheduled according to a fixed delivery plan. The input to the delivery plan was adjusted to fit the demands from the construction site. Materials were ordered beforehand because of long delivery times and then pushed to the construction site. This secures, if on schedule, a Just-In-Time delivery. Since only minimal storage was available at site, construction delay had caused materials to be put on stock elsewhere. This has been quite expensive.

4) After the meeting with the subcontractors a meeting with the foremen was held. All foremen with relations to the site were represented at the meeting. Here, the current stage of the production was measured. Completed and non-completed activities were very briefly registered but PPC was not calculated. Furthermore, no effort was made to determine root causes for non-completion, and no effort was made to learn from root causes. To speed up the scheduling process the site-manager at the meeting presented a draft. The draft was based on feedback from subcontractors and the Look-ahead schedule respectively. The Weekly Work plan and possible constraints were afterwards discussed, and the final work plan was drawn in collaboration. The plan had a two week span and was based on the current stage of the construction site and the Look-ahead plan. Since no making ready process was used, it was a risk that both sound and non-sound activities could end up in the Weekly Work plans.

4.2 Case two – Educational institution

1) Phase Scheduling was conducted as a part of a kick-off meeting before the actual start of the on-site production. The Phase Scheduling process did adhere to theory. The PostIt method was applied where all contractors collaboratively set the sequence.

2) The Phase schedule formed the starting point for the main activities and sequence in the Master Schedule. The Master Plan was at first only drawn as a cyclogram. Because the craftsmen had difficulties in reading the cyclogram a traditional Gant-map was made available. The Master Plan was updated by the site engineer when needed.

3) The Look-ahead schedule was conducted as a sliding schedule containing a more detailed 10 weeks window of the Master Plan. Each Wednesday the plan was updated at a construction meeting where contract managers or foremen from most of the contractors were represented. To follow up on the making ready process the status of all activities were controlled and constraints according to the seven preconditions were noted, if critical, the person responsible was noted as well. The actual making ready process was done by the responsible contractor. Resources were in general delivered when needed in relation to space limits and actual demands. No direct buffer or backlog of sound activities was applied during the meeting. Some contractors applied individual buffers; others just regulated the manning to fit demands. Additionally, communication and collaboration between the contractors and the site engineer secured a steady workflow.

Materials were delivered in relation to a fixed delivery plan. Basic items were delivered on a day to day basis and pulled to the construction site. The delivery plan was adjusted to fit the demands of the construction site in relation to the Just-In-Time principal. The size of the order depended on economical considerations. Often long delivery times forced the site-manager to order materials long before needed in production and pushed towards the construction site. Because of limited storage capacity materials delivered too early have to be put on stuck elsewhere. Too late or delayed delivery entailed that production stalled.

4) The Weekly Work Plans were updated every Thursday as a part of a LPS meeting. All foremen with relations to the site were represented at the meeting. First, an evaluation of the last week's work was made. Here, the activities were divided into completed and non-completed, and the responding PPC value was calculated. Furthermore, reasons for non-completion were identified in relation to the seven preconditions. But no effort was made to find root-causes or to learn from mistakes.

After evaluating last week's schedule the schedule for the work plan of the following week were completed based on the Look-ahead plan. Sound activities or "at risk" activities were selected and according to the main sequence placed in the Weekly Work Plan. Where "at risk" activities were activities which still had remaining constraints. These constraints were expected to be removed before the activity started, see Liu and Ballard (2008). The great detail level secured a high quality of the work plans. The downside was prolonged meetings (up to two hours), which resulted in falling concentration.

4.3 Case tree - Nursing home

1) Neither Phase scheduling nor the PostIt method was applied at the construction project. Instead the sequence was continually discussed and only finalized shortly before a new construction phase began. The sequence was determined in collaboration with the involved subcontractors. Furthermore, the sequence was updated when external circumstances required it. A visit from the Danish Working Environment Authority (DWEA) resulted in an immediate stop of the mason-contract. Due to safety precaution DWEA required changes in the work sequence.

2) The Master Plan was conducted before any sequencing had begun. The Master Plan was drawn as a traditional Gant-map and was very detailed. It contained own as well as other prime contractors' production. The Master Plan was not updated as the construction process proceeded. Instead changes were incorporated as a part of the construction meetings.

3) Every Thursday site meetings with subcontractors were held. Here, next week's work was planned. All contract managers were represented. First the stage of the production was evaluated by listing the completion stage of the major activities in percentage. Simultaneously constraints were noted and discussed in plenum. But no PPC calculation was made and no interest was on determining root-causes or to learn from failure. Afterwards the site manager had a short list of obstacles and regulation for the construction site. The purpose of the list was to secure that the construction process was kept running. Finally, manning and downtime were noted.

The Look-ahead schedule was conducted as a 5 week window from the Master Plan. The schedule was completed in collaboration and based on the current stage of the construction process and on the Master Plan. At the meeting the forthcoming activities were very shortly reviewed and possible constraints were noted. Even though focus was on securing sound activities, the seven preconditions were not applied. It was the individual contractor's own responsibility to secure that their activities were made sound. No direct buffer or backlog of sound activities was applied during the meeting. The subcontractors might use small individual buffers, but most likely the manning was used as an instrument to fit actual demands.

Delivery of materials was primarily based on the pull principal c.f. the Just-In-Time principle. Because of long delivery times most deliveries were scheduled in a delivery plan but with a flexible delivery date. Some deliveries such as brick beams or concrete elements were based on

a close to fixed delivery date. Small orders such as stones or insulation were delivered ad hoc when needed.

4) To schedule the actual work plans a meeting was held every Monday. All relevant foremen participated. First a quick registration of the status of ongoing activities took place. This was to ensure that current work was running according to work plan. Thereby problems were spotted giving the site-manager the possibility to intervene. Simultaneously activities were coordinated and the related work plan was created. The Weekly Work Plans were conducted in collaboration and with a two week span. The schedule was based on the completions stage found at the subcontractors' meeting and on a two week printout from the Master Plan. Basically this printout contained all activities regardless sound or not. No focus was on the making ready process or the seven preconditions. Instead constraints were found by discussing the work tasks in plenum.

4.4 Additional Scheduling

The description of LPS management above only presents the general guidelines for the structured management on site. Additionally, a lot of unstructured scheduling and planning was conducted on-site. The site manager continuously followed the progress and through communication and collaboration controlled and coordinated the workflow. Here, the Weekly Work Plans only included the overall work tasks. The site manager talked with the craftsmen as well as foremen and contract managers. He made or arranged agreements between subcontractors. These arrangements were extremely important in the attempt to keep the production running. Without this continuous coordination of the workflow, the production would come to a standstill.

5 Discussion

The research presented is a continuation of research made by Lindhard and Wandahl (2012), who applied a quantitative research to measure the application of LPS in the Danish construction industry. This research dig deeper into the issue and investigates how the applied tools are used in daily work. By comparing the daily use of the applied elements with theory both correct and non-correct usage is identified.

To get a conspectus of the results from Lindhard and Wandahl (2012) the application-level of the different elements in LPS is presented in Table 2. Furthermore, the applied elements from the three case studies are summed up and in the table. A quick comparison of the results shows similar trends. Only parts of LPS are applied, mostly the overall scheduling system containing the 4 main plans. Thus LPS is in both studies not applied as a complete system.

Every element in LPS serves a purpose. Therefore omitted elements have to be substituted by elements having a similar effect. The case studies showed that sometimes parts of the traditional or old management system are applied instead. It is important to notice that the elements in LPS are designed as a complete system and that these old elements often do not provide the same information. For instance PPC calculation was substituted with a traditional stage evaluation. This preclude the finding of root-causes and learning from failure. Therefore, limited implementation of LPS is critical. Lindhard and Wandahl (2012) state that *“a partly applied LPS can be a main barrier to increased reliability in the scheduling process.”*

Table 2 Applied elements of LPS where the results from the questionnaire research in Lindhard and Wandahl (2012) are compared with the case study. Brackets mark that the element is applied only to a minor degree.

	Questionnaire research by Lindhard and Wandahl (2012)		Case studies			
	Respondents (n=)	Percent (n/N·100=)	Case 1	Case 2	Case 3	Total
Weekly Work Plans	34	91,9%	√	√	√	100%
Lookahead Plan	32	86,5%	√	√	√	100%
Phase Schedule	31	83,8%	√	√	%	66,7%
Master Schedule	30	81,1%	√	√	√	100%
The seven preconditions	25	67,6%	%	√	%	33,3%
Sequencing (PostIt)	20	54,1%	√	√	%	66,7%
PPC	18	48,6%	%	√	%	33,3%
Pulling (Just In Time delivery of materials)	14	37,8%	%	%	(√)	33,3%
Buffering	12	32,4%	%	(√)	%	33,3%
Learning (PPC)	11	29,7%	%	%	%	0%
Total (N=)	37	100,0%				

In the following four sections, the actual use of the applied elements of LPS is compared with theory.

1) Two of the three case studies had applied Phase scheduling. Both projects had applied the PostIt method to determine the sequence in collaboration with the subcontractors. In both cases usage of the applied elements did correspond to theory.

2) In every one of the three case studies a Master Schedule was drawn. Phase scheduling did when applied form the foundation to the Master Plan. However in one out of the three cases the Master Plan was not updated. According to LPS theory, scheduling should be rethought when conditions change and dealt with in time (Tommelein 1998). If the underlying sequence is not rethought the Master Schedule loses its value as a guiding tool. But even more critical, it can result in a poor sequence which causes problems in the execution phase, affects interdependencies between subcontractors, and result in a more expensive construction project. Therefore, it was positive that the underlying sequence in all three cases was rethought.

3) The Look-ahead Plans were applied as a sliding schedule. They were drop-outs from the Master Schedule, but with varying size. At the Look-ahead level there was a greater need for detail. Therefore, the number of activities compared was expanded. In two out of the three cases the Look-ahead plan was completed in collaboration with contract managers and sometimes foremen. In the last case the plans were briefly presented, after which the involved subcontractors had an opportunity to make comments. Lindhard and Wandahl (2012) recommend the use of foremen in the Look-ahead planning to bring in “*enlightenment*” of the execution process and, thereby, increase the quality of the plan.

In one of the three cases the making ready process had no attention. In one case the making ready process had minor attention where constraints were discussed in plenum. And finally, in one case the making ready progress was determined. At individual level activities were examined for constraints. This was done by using the seven preconditions. It should be noticed that this was the only case where the seven preconditions were applied by management. However, in one case the preconditions were mentioned at the kick-off meeting.

In all three cases the actual making ready process was delegated to the responsible subcontractor. But without proper introduction and support by management the seven preconditions cannot be expected to be applied by subcontractors. The seven preconditions are key elements in the sounding process. If not applied the making ready process will not be proceeding satisfactorily. Without the making ready process there is no guarantee that only sound activities end up in the Weekly Work Plans. Thereby, unreliability has entered the schedule and productivity will decrease.

Buffering was only to a minor degree used by management and only in one of the three cases. The buffering processes were not structured and seemed to be a casual consequence of too much ready work. Additional buffering had to be performed by the responsible subcontractor. Buffers serve as a shield against variation and are an essential element in LPS. Without the buffers non-productive time will increase.

In all three cases material deliveries were scheduled according to a fixed delivery plan. Here, long delivery times force the site-manager to order materials long before needed. Combined with uncertainties in the production flow long delivery times make the construction site vulnerable for changes. The flexibility of the delivery plan varied from project to project and was depending on material type. In two of the three cases the flexibility was close to insignificant. This has caused materials to be delivered before needed. Furthermore, limited storage capacity at site resulted in material put on stock elsewhere. This entails increased costs for storage which also induces rehandling of materials.

4) In one of the three cases, a PPC calculation was performed to follow up on last week's work. In one case the stage was measured by a very brief registration of completion or non-completion of main activities. In the last case the stage was monitored by stating a "*percentage complete*" of major activities. Every method enables the site-manager to follow the progress on site. Additionally, by applying PPC it is easy to compare progresses and to early detect problems. Here a decreasing PPC reveals problems at the construction site.

Root causes for non-completion were only found in the case which applied the PPC measurement. But no learning from root causes was applied. By looking into the root causes, problems can be understood and repetitions avoided. Learning from failure is a key to gain improvements in productivity.

The Weekly Work Plans were completed in collaboration between foremen and site-manager. Since no backlog of sound activities were applied. Activities from the Look-ahead plan were in all cases directly moved to the Weekly Work Plans. The site-managers' main concern was to secure a steady workflow at subcontractor level. Therefore, "*at risk*" activities were often moved into the work plans. The backlog was introduced to ensure that only sound activities end up in the work plans, and is a key element in LPS. Therefore, combined with "*at risk*" activities, it was not a surprise that unsound activities ended up in the work plans. Thereby the reliability of the plans decreased and thus caused the productivity to decrease.

However it has to be emphasized that varying preconditions have an impact on soundness. A change in just one of the seven preconditions is enough to change the soundness of an activity (Lindhard and Wandahl 2011). Especially problems with varying manning related to illness were registered. Moreover complex tasks and limited time can be the cause for constraints being overlooked (Lindhard and Wandahl 2012).

Introductory, 12 implementation challenges to LPS were presented (Vishal *et al.* 2010). By exploring the everyday application of LPS virtually all 12 challenges have been involved. But two factors have proven to be of particular importance. Most of the above mentioned 12

challenges can be managed by increasing either the willingness to succeed or knowledge. More energy, power and stubbornness need to be put behind the implementation and anchoring process. But without adequate knowledge about LPS energy will be wasted. Therefore, the first step is to increase the knowledge about LPS. LPS needs to be understood, and understood as a complete system.

6 Conclusion and Further Research

A previous quantitative research has shown that LPS is often only implemented partly. This research is applying a qualitative research technique. Based on three case studies application and usage of the elements in LPS was examined. In both studies an only partly implemented LPS is ascertained. Hereby, the results support the previous, and the triangulation effect adds validity to the results.

As an answer to the research question daily application was afterwards compared with theory. One positive finding compared to the questionnaire survey was that foremen were participating in the scheduling process. In general most of the applied elements, including the 4 main schedules, were applied correctly. But the connections and interactions between the plans especially the Look-ahead and the Weekly Work Plans did not always function as intended.

The backbone in LPS, the making ready process, did not have enough focus. Hereby the purpose of LPS, to bring validity into the schedule, is not achieved. Furthermore, the rules of the making ready process were not observed. No buffering were applied and “*at risk*” activities were moved directly to the Weekly Work Plans. The responsibility of the individual making ready process lies at the responsible subcontractor. But (s)he should not be left alone. In order to secure a working sounding process the site-manager should introduce and support the subcontractors in the making ready process including the seven preconditions.

In none of the three cases learning was applied. Learning from mistakes is a key to improvements in the construction industry. No learning fits well with the conservatism in the construction industry in general. Here only minor improvements in productivity have been achieved in the last decades.

Often the site manager is free to choose his own methods, this increases the likelihood for misunderstandings and misuse of LPS if implemented. A lack of guidance and support from top management increase the need for knowledge. To overcome the implementation challenges especially two factors have been found important: willingness to succeed and knowledge. Knowledge is important to secure a correctly implemented and applied system, while willingness or stubbornness is important to maintain and anchor changes deep into the organizational behavior.

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IMPROVING THE MAKING READY PROCESS - EXPLORING THE PRECONDITIONS TO WORK TASKS IN CONSTRUCTION

Søren Lindhard¹ and Søren Wandahl²

ABSTRACT

Scheduling in construction is complex. Before an activity can be conducted, a number of preconditions first have to be fulfilled. In Last Planner System this removal of constraints is referred to as the making ready process. To ensure that this process is running, the preconditions need to be known. Therefore, in an attempt to bring these preconditions into light three construction projects have been followed. Here reasons for non-completed activities have been collected. In total 5014 activities have been registered whereof 1279 was not completed according to schedule. Afterwards the non-completed activities were sorted into nine main categories. The six of the categories are basically corresponding to the ones presented by Koskela (1999), while the last three are an expansion of Koskela's external condition category. The preconditions are as follows: 1) Construction design and management. 2) Components and materials are present. 3) Workers are present. 4) Equipment and machinery are present. 5) Sufficient space for conduction. 6) Previous activities must be completed. 7) Climate conditions must be in order. 8) Safe working conditions in relation to national "Health and Safety at Work Act" have to be present, 9) Known working conditions. Often a problem during excavations or refurbishment assignments where existing conditions first has to be examined. One of the major and underlying reasons to non-completed task is insufficient and even bad scheduling. Often non-sound and out of sequence activities are selected to the Weekly Work Plans. When conducting the schedule it is important to notice as described in Lindhard and Wandahl (2011) that the soundness of an activity can vary over time. By focusing on all nine preconditions a more robust schedule can be achieved. A more robust schedule induces an increased percent planned completed level and moreover and increased productivity.

KEYWORDS

Lean Construction, Preconditions, Constraints, Last Planner System, Making Ready,

INTRODUCTION

Lately production in construction is undergoing a transition from traditional construction to Lean Construction. This includes among others the implementation of Last Planner System (LPS). Since LPS is based on Lean-thoughts, these thoughts gains acceptance in the industry. One of the central elements in lean is the focus on

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product flow and the elimination of non-value adding activities; in other terms removal of waste. Ohno (1988) stated that the total capacity of a production system equals the sum of work and waste, he furthermore identified seven different types of wastes. These are showed at the list below. In the list the first five elements refers to the material flow while the last two refers to the human work flow (Koskela 2000).

- Waste of overproduction
- Waste of stock on hand (Inventory)
- Waste of transportation
- Waste of making defective products
- Waste of processing itself (Over-processing)
- Waste of movement
- Waste of time on hand (Waiting)

Waste can be categorized into both necessary and unnecessary waste, where necessary waste still is necessary for production. Necessary waste is still waste and should be minimized. An example on waste which sometimes is necessary could be transportation (Choo and Tommelein 1999). Choo and Tommelein (1999) furthermore claims that transportation sometimes can be cost-saving for instance when transporting materials to more effective off-site production facilities.

Additionally both Christiansen and Ahrengot et al. (2006) and Koskela (2004, 2000, 1999) suggests extra sources to waste. The suggestions include: not to fully utilize the mental capacity of the employees, making-do where assignments are started when at least one input is ceased, and work performed in suboptimal conditions. Koskela (1999) lists a number of conditions which leads to suboptimal working conditions: Congestion, out-of-sequence work, multiple stops and starts, inability to do detailed planning in advance, obstruction due to material stocks, trying to cope without the most suitable equipment for the task, lack of planning and preparation, interruptions due to lack of material, tools or instruction, overtime, oversizing crew.

Implementation of Last Planner System (LPS) on construction sites has induced a growing interest in construction constraints. If the constraints are not removed they will lead to unnecessary waste which will surface as waiting, movement, transportation etc. Therefore, construction constraints do have a central role in the making ready process (Lindhard and Wandahl 2012). The purpose of the making ready process is to make activities sound. The making ready process starts when activities enter the Look-ahead window. Here, focus is on the individual activity where constraints are identified and removed (Jang and Kim 2008).

When all preconditions are fulfilled an activity is moved to a backlog of sound activities. When conducting the Weekly Work Plans only activities from the backlog are selected. This secures that only sound activities are moved to the Weekly Work Plans (Hamzeh *et al.* 2008; Steyn 2001; Ballard 2000; Howell and Ballard 1994). According to theory the backlog should be kept at minimum two weeks (Ballard 2000). This is to ensure that enough sound activities can be moved to the Weekly Work Plans to match capacity and moreover enough ready work to buffer against unexpected constraints in the sound activities (Ballard 2000; Ballard 1997).

If just one precondition is not fulfilled an activity is not sound and cannot be conducted. Without the making ready process and without proper knowledge to the preconditions there is no guarantee that only sound activities end up in the Weekly Work Plans. Thereby unreliability has entered the schedule which leads to a high level of non-conformances and results in demotivated workers and moreover productivity decrease (Ballard 1994). To secure that the sounding process is progressing, in order to maximize productivity, the site-mangers need to know and understand the preconditions in construction.

There is a need for exploring the preconditions in construction in order to understand and improve the making ready process. The preconditions to ready work were first mentioned by Koskela (1999) which found seven preconditions. Koskela's seven preconditions are listed below.

- 1) Construction design; correct plans, drafts and specifications are present
- 2) Components and materials are present
- 3) Workers are present
- 4) Equipment and machinery are present
- 5) Sufficient space so that the task can be executed.
- 6) Connecting works, previous activities must be completed
- 7) External conditions must be in order.

Studies indicate that implementation of LPS leads to an improvement in project productivity (Formoso and Moura 2009; Friblick *et al.* 2009; Ballard 2000; Garza *et al.* 2000; Ballard 1999). As mentioned one key element in LPS is the making ready plans which purpose is to reduce the unreliability of the schedule. Implementation of LPS has raised percent planned completed (PPC) to around 70 %. But the PPC level is right now stuck at the 70% level. To help construction in reaching a higher PPC level, it is important to understand what causes the non-completion of activities. Therefore, in order to reach the 90 % level or higher the preconditions needs to be explored to enhance the understanding of existing and reveal undiscovered preconditions (Ballard 1999; Ballard 2000; Lindhard and Wandahl 2011).

The preconditions in construction are examined through three case studies. Here causes for not started and not completed activities are registered and categorized. The result is a framework for the focus areas in the making ready process. This helps the site-manager in securing that only sound tasks end up in the Weekly Work Plans and thereby increases the quality and the reliability of the plans. The preconditions in construction are examined through the following research question:

What are the preconditions to the conduction of construction activities in onside production?

RESEACH METHODOLOGY AND METHODS

Three construction sites are followed focusing on observing and registering reasons for non-completed activities. This was done in order to map the preconditions to construction activities in onside production. The cases had to fulfill two basic requirements: Last Planner Systems must be applied, and PPC calculation must be

conducted. Furthermore, since most data are from archives, reasons for non-completion or non sound activities had to be described. To secure consistency all three construction projects are with the same site manager in charge. In the selection process, mail correspondences and phone conversations with site managers and company consultants secured the fulfillment of the mentioned requirements.

Data is collected through either LPS meetings or archived summaries from LPS meetings. This is because the PPC calculation and collection of reasons for non-completion take place at the LPS meetings. The LPS meetings do furthermore involve the Look-ahead planning and the scheduling of the next weeks plans which in relation to LPS-theory are completed in collaboration. The use of archives secures collection of data from the entire construction period.

The reason to supplement the archived data with onsite observations was to get an insight to how the meeting actually proceeded and how non-completions were recorded. Therefore, the archived data was in one of the construction cases supplemented with on-site observation, meeting participation, and semi and unstructured interviews. Since all cases have the same site manager in charge, insight in the scheduling process from all projects is achieved.

The data analysis consists of categorizing the recorded causes to non-completions into main categories. This is done to get an overview to causes to non-completion and to simplify the problem to help avoiding future repetitions. Data collection from the three cases is listed in **Error! Reference source not found.** which is followed by a short case description.

Table 1: Data collection at the three case-studies

	Case 1	Case 2	Case 3
Contract form	Turnkey contractor	Turnkey contractor	General contractor
Project followed	Entire construction period	23 weeks	Entire construction period
From archives	Reports from LPS meetings	Reports from LPS meetings	Reports from LPS meetings
Construction period	53 weeks	23 weeks	60 weeks
Activites registered	1829 activities	593 activities	2592 activities
Non-competions	575 activities	134 activities	570 activities
Average PPC	68.6 %	77.4 %	78.0 %

CASE ONE - EDUCATIONAL INSTITUTION

Case one was construction of an educational institution. The project consists of two buildings in total 11000 m². The main building was a three-storey building plus basement, in total 8000 m² and has an autonomous contract value on \$21.75 million. The secondary building was a two-storey building with no basement, in total 3000 m². In total the secondary building had an autonomous contract value on \$7.36 million. The duration of the construction process was restricted to 16 months.

CASE TWO - EDUCATIONAL INSTITUTION

Case two was a renovation project of an educational institution. The project original only involved a renewal of the roofing. But as renovation progressed extra work arose. Therefore, the project ended up additionally involving renovation of windows, inner walls, and sewer. In total the project contract value ended at \$4.88 million, with a fixed schedule to 9 months.

CASE TREE – HOUSING

Case three was a renovation project of 9 residential apartment blocks containing a total of 300 flats distributed at 32 stairways. The flats were, because of variation in storey and size, irregular distribute in the blocks. The contract included renovation of facade and renewal of the roofing. The project contract value was \$28.62 million, with a duration fixed on 25 months.

THE 9 PRECONDITIONS OF CONSTRUCTION

The collection of data from the three case studies revealed a lot of different preconditions. These are sorted in to 9 different groups of preconditions and presented in the following. In total 5014 activities have been registered whereof 1279 was not completed according to schedule. Nine different groups or categories of preconditions have been applied in an attempt to categorize the non-completed activities. The first six is basically corresponding to the ones presented by Koskela (1999), while the last three categories are an expansion of Koskela's (1999) external conditions. 1) Construction design and management; correct plans, drafts and specifications are present. 2) Components and materials are present. 3) Workers are present. 4) Equipment and machinery are present. 5) Sufficient space so that the task can be executed. 6) Connecting works, previous activities must be completed. 7) Climate conditions have to be acceptable. 8) Safe working conditions in relation to national laws have to be present, 9) Known working conditions. Often a problem during excavations or refurbishment assignments where existing conditions first has to be examined.

One of the major and underlying reasons to non-completed task are insufficient and even bad scheduling. Often non-sound and out of sequence activities are selected to the Weekly Work Plans. When conducting the schedule it is important to notice as described in Lindhard and Wandahl (2011) that the soundness of an activity can vary. By focusing on all nine preconditions a more robust schedule can be achieved. A more robust schedule induces an increased PPC level and moreover and increased productivity. The actual recorded reasons to non-ready work assignments are in the following elaborated in relation to the 9 groups.

1 CONSTRUCTION DESIGN AND MANAGEMENT

- a) Sufficient and correct plans, drafts, and specifications have to be present.
 - a. Drawings with wrong measurements
 - b. Outdated drawings
 - c. No clarification of project details
 - d. Missing approval of project design or details.

- b) Legal Aspects
 - a. Government authorizations
 - b. Building laws and Eurocodes
 - c. Contracts and agreements
- c) Communication, coordination, collaboration, and individual mistakes
 - a. Misconceptions and oblivions
 - i. High work pressure
 - ii. Lacking skills/experience
- d) Adjustments in the schedule
 - a. Changes made to optimize the sequence
 - b. The conducted schedule is not realistic, cannot be executed
 - c. Changes in soundness of activities forces changes to be made
 - d. A complex and changing environment forces the schedule to be rethought.
 - i. Unexpected conditions causing need for adjustments
- e) Incorrect time estimate
 - a. Activity takes longer or shorter than expected

2 COMPONENTS AND MATERIALS

- a) Correct materials
 - a. Wrong materials were delivered
 - b. Materials were not delivered
 - c. Materials does not fit the purpose
 - i. Drying of materials necessary because of moisture
- b) Materials are not present when assembling
 - a. Dwelling materials in the stock.
 - b. Materials damaged in stock or during assembly

3 WORKERS

- a) Workers need to be present
 - a. Illness in the workforce
 - b. Unexpected or overlooked vacation.
 - c. A contractor does not keep his commitments and do not show up.
 - i. Forgets the agreements
 - ii. Keep his own schedule, and make adjustments
- b) Workers need to be qualified
 - a. Changes in the workforce.
 - i. Working slower than expected.
 - ii. Resulting in low quality and forcing rework

4 EQUIPMENT AND MACHINERY

- a) The correct equipment and machinery are present.
 - a. Equipment are not delivered or delayed
 - b. Equipment used by other contractors
 - c. Wrong equipment or not fitting the work task.
 - d. Breakdowns in equipment

5 SUFFICIENT SPACE

- a) No space for completing the activities.
 - a. Not enough space
 - b. Space has to be shared with other contractors.
 - c. Not suitable work surroundings
 - i. No stable base for assembling or driving
- b) Access to workplace
 - a. Work area was locked
 - i. No key

6 CONNECTING WORKS

- a) Completions of connecting activities
 - a. Is caused by including “*at risk*” activities in the Weekly Work Plans
 - i. Previous activities was not completed according to plan
 - b. Rework in previous activities caused delay.
 - i. Rework caused by insufficient quality of work
 - ii. Rework caused by damages to completed work

7 CLIMATE CONDITIONS

- a) Weather conditions
 - a. Temperature conditions not allowing certain work task to proceed
 - b. Moisture conditions in the building
 - c. Rain or weather conditions forcing work task to stop
 - i. Drainage of the construction causing delay
 - d. Snow or frost hindering activities to start.
 - i. snow clearing is causing delay

8 SAFE WORKING CONDITIONS

- a) Safe working conditions needs to be present
 - a. The national “Health and Safety at Work Act” is not obeyed
 - i. Problems with fencing
 - b. Work accidents forcing work to stop

9 KNOWN WORKING CONDITIONS

- a) Unknown working conditions causes changes in plans
 - a. Unexpected discovery of asbestos or rot
 - b. Unexpected soil conditions
- b) Drawings are incorrect or outdated
 - a. Unexpected condition of existing structure

The content in the nine preconditions above, gives a picture of the most common reasons for non-sound activities in construction. It is important to state that the list is

based on research from three construction projects and is not considered exhaustive. Furthermore, specifics will differ depending on the actual construction project.

DISCUSSION

It is essential in the sounding process that the site manager is aware of the preconditions which can affect the soundness of an activity. Else preconditions can be overlooked resulting in interrupted workflow and decreased productivity. The three construction case studies have revealed a number of reasons to non-sound activities. These reasons were afterwards divided into 9 main categories extending the previous conception. Koskela's (1999) external condition category was divided into three new categories respectively: Climate condition, safe working conditions, and known working conditions. Finally, the construction design category is expanded to also contain conditions caused by site management.

It can be argued that the three new categories are just subcategories to the existing 7 preconditions being a part of the external condition category. The existing external conditions category covered several fundamental different subcategories. Therefore, the three new categories are considered necessary to achieve a sufficient detail level and to bring awareness and attention to the variety of sources to not sound activities in construction. Splitting external conditions up into 3 categories: climate, safety, and unknown will help site-managers making activities ready. Awareness could be achieved by putting a concrete name on the main reasons to non-completion in onsite construction. From this follows that the likelihood of unexpected constraints in sound activities will decrease leading to an increased PPC level.

The causes to non-sound activities will vary depending of the type of construction project. Projects involving refurbishment will more often experience unexpected conditions as asbestos in the existing construction. Due to the limited number of case studies and due to variation in the causes depending on construction type the list is not considered exhaustive.

When making activities ready for conduction for instance by following the list above it is important to state that the activities should be ready for completion. By stating completion it is not enough to secure an activity can be started. This could for instance be only limited delivery of materials. Such an activity will be considered as an “*at risk*” activity because it still carries constraints and thereby increases the likelihood for non-completion (Liu and Ballard 2008).

Even though all constraints are removed preconditions change (Lindhard and Wandahl 2011). Machinery breaks down, weather changes, unexpected needs of materials etc. This changes the soundness of the activities in the Weekly Work Plans, and hinders the scheduled activities to proceed. To keep production going, LPS has implemented the 14 days buffering. PPC calculation is only measuring the quality of the schedule and neither the production stage nor productivity. To increase the PPC level, the responsible contractor should during the week follow up on the preconditions and make sure that the scheduled activities can still finish on time.

CONCLUSION AND FURTHER RESEARCH

Based on three case studies the preconditions to the completion of activities in construction were examined. The research revealed a number of reasons for non-sound activities. These were divided into 9 main categories and thereby extending the previous conception with two extra categories. Here, the external conditions category was divided into 3 categories: Climate conditions, safe working conditions, and known working conditions. Furthermore, the category including construction design was expanded to also contain constraints caused by site management.

By dividing the external condition category into three subcategories a sufficient detail level in the categories is achieved. A sufficient detail level secures awareness and attention to the variety of sources to not sound activities in construction. Putting a concrete name on the main reasons to non-completions increase the awareness and helps the site-manager not to overlook remaining constraints in the sounding process. Therefore, the three new categories will help archiving a more robust schedule. A more robust schedule induces an increased PPC level and moreover and increased productivity.

It is important to state that the list presented above is not considered exhaustive. Constraints may vary depending on the type of construction project i.e. refurbishment, housing, offshore etc. Further research need to be carried out to verify the completeness. In future research attention could be on what triggers non-completion in relation to the 9 different preconditions, for instance by applying the 5 whys.

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THE ROBUST SCHEDULE – A LINK TO IMPROVED WORKFLOW

Søren Lindhard¹ and Søren Wandahl²

ABSTRACT

In today's construction, there is a paramount focus on time, and on the scheduling and control of time. Everything is organized with respect to time. The construction project has to be completed within a fixed and often tight deadline. Otherwise a daily penalty often has to be paid. This pin-down the contractors, and force them to rigorously adhere to the initial schedule. If delayed the work-pace or manpower has to be increased to observe the schedule. In attempt to improve productivity three independent site-mangers have been interviewed about time-scheduling. Their experiences and opinions have been analyzed and weaknesses in existing time scheduling have been found. The findings showed a negative side effect of keeping the schedule to tight. A too tight schedule is inflexible and cannot absorb variability in production. Flexibility is necessary because of the contractors interacting and dependable activities. Variability is delaying the process and resulting in conflicts between the trades. Moreover, a tight schedule does to a higher degree allow conflicts to be transmitted from one contractor to another. This increases the number of hot spots between contractors and produces more conflicts. The result is a chaotic, complex and uncontrolled construction site. Furthermore, strict time limits entail the workflow to be optimized under non-optimal conditions. Even though productivity seems to be increasing, productivity per man-hour is decreasing resulting in increased cost. To increase productivity and decrease cost a more robust schedule is needed. The solution seems obvious, more time has to be relieved and more robustness has to be put into the schedule. The downside is that a postponed completion data often results in other costs for the client. Therefore, the deadline has to be set realistic. By introducing flexibility into the deadline negotiations can help achieving win/win situations bringing productivity and value creation up.

KEYWORDS

Lean Construction, Robustness, Work flow, Interview

INTRODUCTION

In construction as well as everywhere else "*time is money*". Therefore, time is a competitive parameter and often the most important one. Everything is planned with concern to time. The contractor is in his contract forced to finish the project to a fixed completions date. If not daily penalties have to be paid, and the contractor is in risk for not allocating resources to other future assignments.

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Time also serves as a central part in Lean Construction where any unnecessary time consumption is regarded as waste, c.f. the seven types of waste (Ohno 1988; Suzuki 1987). The Lean approach is through transformations focusing on adding customer value to the end product. Meanwhile non value adding activities such as moving, waiting, and inspection are sought eliminated (Koskela 2000).

The scheduling tool Last Planner System (LPS) has been implemented at construction sites in the attempt to remove waste to make the production Lean (Ballard 2000a). A part of LPS is the Phase Scheduling process. Here the individual contractors collaboratively determine the sequence, bearing interactions and dependencies in mind (Ballard and Howell 2003; Ballard 2000b). The purpose of the sequencing process is to streamline the production and thereby remove waste. Through the making ready process, activities are made ready for completion (Jang and Kim 2008). This is done to decrease variability and thereby achieve robustness in the schedule. But still with respect to the fixed completion date.

Transition from traditional time scheduling to LPS, has increased the number of planned activities completed (PPC). Before LPS was introduced, the PPC level was approximately 50 %, after implementation the PPC raised to around 70 %. Furthermore, a decrease in non-productive time from 50 % to 35 % was recorded (Ballard 1999). Non-productive time only includes the loss of productivity which can be assigned to delays and rework. Indeed there is still, both reliability in planning and more essential productivity to be achieved (Lindhard and Wandahl 2012). Still 30 % of all planned activities do not finish as planned and still only 65% of all time is productive.

One way to increase the robustness of the schedule and thereby the PPC measurement could be by improving workflows. Even though LPS tries to manage and improve the workflows a change in the completion date is not considered. An extended deadline would decrease dependencies between contractors leading to a less complex construction project. The complexity is caused by highly interdependent activities, a lack of standardization, multiple components, limited space, and many trades and subcontractors represented on site (Ahmad and An 2008; Bertelsen and Koskela 2004; Bertelsen 2003; Ballard and Howell 1995). Thus leading to a production where different contractors perform overlapping and interacting activities. The result is increased uncertainty which make the construction process very difficult to schedule (Salem *et al.* 2006; Bertelsen 2003; Lindhard and Wandahl 2011).

This research looks into what happens if the pressure of time is relieved. The interdependencies will still exist but the number of joints would be reduced. This reduces the number of conflicts. By extending the deadline a gap between interdependencies would make it more easy for the contractor to finish on time. Moreover if enough time is released the gaps will increase which make it possible to optimize the work of the contractors more individually. This creates a situation where suboptimization is acceptable as long as the total process still is kept in mind. Finally, extra time would allow contractors to select cheaper production processes.

It is important to stress that an extension of the construction period also would cause negative effects. Firstly, there could be costs related to an extended deadline, for instance rental of other constructional facilities or loss of income. Secondly, the construction process might be more expensive since the rental period of heavy equipment might be prolonged. Therefore, the client has the final call when determining the completion date.

In an attempt to develop new approaches to supplement the existing scheduling tools the following research question is raised.

“What happens to a construction project if more time is released? And could “win/win” situation be gained if more focus, with time consumption in mind, is on securing a more optimal process?”

The answer to this question is found by interviewing experienced site managers and by looking into the theories of Lean Construction.

RESEARCH METHODOLOGY AND METHODS

Different research approaches capture different aspects from the world of construction sites. One approach is to capture knowledge by interviews or conversations. According to Burgess (1982) conversations are a crucial element in a field research. It is important to notice that interviews are more than a conversation it is a conversation with a purpose (Ritchie *et al.* 2005; Dexter 1970). Interviews can be “used to make sense of and understand, on a daily basis, the world in which we live” (Ritchie *et al.* 2005, p.100). They can be used to capture experiences from people and understand what meaning they make out of their experiences.

Interviewing is an approach to learning (Rubin and Rubin 1995). Kvale (1996, p.14) state it like this: “*the qualitative research interview is a construction site for knowledge*”. During the face to face interchange the interviewer is trying to elicit the needed information (Maccoby and Maccoby 1954).

Three site managers were interviewed in an attempt to capture their experiences with LPS to learn from practitioners (Seidman 1998). Therefore, when selecting interviewees it was a basic requirement that LPS was applied in a daily basis at current construction site. The interview was conducted as semi-structured following the interviewing guidelines presented in (Ritchie *et al.* 2005, p.106). The interviews were conducted individually for every site manager as a face to face interview. Before the interviews were conducted the site managers and the interviewer meet in several occasions to gain mutual trust which according to Oakley (1981) is essential. Only the oral communication was of interest. This means that no interest was put into capturing kinesic, paralinguistic, or chronemic data.

Before the interview a number of open questions were prepared to help structuring the interview and making sure all important topics were covered. Wengraf (2004) suggest that open questions are prepared having in mind that questions cannot be planned in detail, since the informants response cannot be predicted in advance.

Therefore, questions must be improvised in a theorized and deliberated way (Wengraf 2004). The interviews were recorded in Danish and supported by additional field notes. Afterwards the data from the interviews were transcribed, analyzed, and translated into English.

RESULTS

In the following section the results of the interviews are presented. The site managers are made anonymous. Instead (B1), (B2) and (B3) respectively represent the three site managers.

LPS is implemented in the seeking of an increased robustness in the scheduling processes. When scheduling, the PPC calculation determines the quality or the robustness of the schedule. Therefore, the site managers (B2) *“seek for a PPC between 70 and 90%”*. This opens up rooms for non-completions which are important. (B2) *“If we do not take risks we get nowhere”*. Collaboration is important and we seek to involve the contractors in the scheduling process. (B2) *“Sometimes the schedule is kept sometimes not, but at least we are trying to schedule.”*

The Phase schedule is very important. (B3) *“By determining the right sequence you speed up production and moreover often increase quality.”* The sequence is tied to the fixed timeframe. (B3) *“It is within that frame the optimal sequence has to be found. (B3)”If no time limits were attached the cheapest solution would probably be that one man had to do all the work.”* Therefore, time needs to be taking into consideration.

Even so the schedule is often too tight. (B3) *“Therefore, things have to be hurried and the result is increased expenses. This is wasted money.”* (B1) *“The more activities you can complete on schedule the better workflow you will get because acceleration of work is cost full.”* If more time were added to the construction process the workflow could be optimized. Maybe the number of trades could be reduced to make the scheduled tasks more foreseeable. With more time (B2) *“We could cut expenses by optimizing the sequence.”*

In construction it is a tendency that (B3) *“contractors work best under pressure. Everything has to be complete in the last possible minute”*. It is a risk that the extra time I wasted. Therefore, one should only carefully extend the timeframe.

Still the timeframe has to fit the project. (B1) *“It is important to be able to keep a robust time schedule without accelerating the work.”* The result of a too tight schedule is increased costs. (B3) *“Sometimes work accelerations forces the selection of foolish solutions where cost is neglected.”* Therefore, a realistic deadline is important when talking total costs of construction. We build what the owner wants. (B3) *“To us work acceleration is waste but it is the owners call to set the deadline.”* But of cause (s)he has other considerations (B3) *“maybe loss in turnover.”*

One thing is cost of accelerated works. Saving could have been gained by selection cheaper production processes. At least the owner should be willing to negotiate to

create a win/win situation. Thereby, savings would probably be gained. The final solution is not so important to us (B2) *“in the end the owner has to pay for what he gets.”* With regards to quality, accelerated work should not have an effect a noticeable effect. (B3) *“We still have to deliver the agreed quality. Therefore, we cannot make compromises which affect the end product.”* But still (B1) *“with more time we could deliver better quality.”*

As a site manager working under pressure, sometimes you make poor decisions. To decrease the number of bad decisions (B3) *“we try to involve the people who are affected by the decision and together find the best solution.”* This has proven very successful.

The low flexibility in project duration is often caused by a very traditional way of thinking and caused by contract bonds. Here, delay is resulting in daily penalties. This daily penalty is often very large forcing the contractor to finish on time. (B3) *“It sometimes even seems like the owner even speculates in daily penalties.”* Therefore, (s)he is of course not willing to give extra time for construction.

THE LEAN CONSTRUCTION THEORY

To show that extend time, even though it is regarded waste, can have a positive effect on the overall productivity the Transformation-Flow-Value (T-F-V) theory is shortly presented. In the T-F-V theory production is viewed as a flow of materials starting from raw materials and ending as the final product. The material flow is undergoing, moving, waiting, inspection, and transformation before the final construction is finished (Koskela 2000; Koskela 1992).

Every activity consists of a cost and time consumption. Only transformations are adding value to the product, the other activities are only expenditures in cost and time and can be regarded as waste. The concept is then to eliminate or minimize waste or non-value-adding activities and to streamline the value-adding activities to make them as efficient and as value adding as possible. (Koskela 1996; Koskela 1992)

Value is a fulfillment of the customer demand and requirements. Johnson & Kaplan (1987) defined value this way: *“value of any commodity, service, or condition, utilized in production, passes over into the object or product for which the original item was expended and attaches to the result, giving it its value.”* To increase value generation customer requirements needs to be defined. Every activity has in general two customers, the following activity and the end customer. To maximize value the needs for both customers have to be determined and during transformations fulfilled (Koskela 1992).

A method to reduce waste is to simplify the process. This includes reducing the linkages and the number of steps in the informational or material flow and reducing the number of parts and components through production. According to Koskela (1992) *“the very complexity of a product or process increases the costs beyond the sum of the costs of individual parts or steps.”* Simplification can be achieved by a reconfiguration of the value-adding activities and by eliminating the waste activities.

Other approaches could be prefabrication, modularization, or standardization of parts and materials etc. Moreover could it be achieved by decoupling linkages, and minimizing the needed information (Koskela 2000; Koskela 1992).

By simplifying the production process variability is decreased. A decrease in variability induces a decrease in the non value-adding activities and improves cycle and lead time (Hopp *et al.* 1990). Schonberger (1986) further stated that: “*Variability is the universal enemy*”. Approaches to reduce variability could be by eliminating the root causes, or by, as mentioned, simplification and standardization (Koskela 2000; Koskela 1992).

Lead time is defined as the sum of time applied to processing, inspection, waiting, and moving. Besides of a reduction of waste, a reduced lead time results in a faster product delivery to the customer and simplifies management. It increases robustness of the system because the recovery from upsets is more rapidly and less wasteful (Ballard *et al.* 2003). A more rapid response to upsets is increasing learning and project control. Thereby the need of buffers shrink, which reduces cost (Ballard *et al.* 2003). Approaches to reduce lead time could be reducing batch sizes, reduce waiting time, minimizing moving distances, smoothing and synchronizing flows, reducing variability, conduct activities in parallel order, or isolate the key value-adding sequence from support sequences (Koskela 2000; Koskela 1992).

An increased flexibility, gives an increased productivity and reliability. It improves the ability to respond on unforeseen events (Ballard and Howell 1995; Koskela 1992). Approaches to increase flexibility could be buffering, customizing as late in the process as possible, reducing difficulties of setups, a multi-skilled workforce, or finely by minimizing lot sizes to closely match demands (Koskela 2000; Koskela 1992). This leads to process transparency, which increases the visibility of errors and the motivation for improvement. Motivation can also be achieved or stimulated by benchmarking. Initiatives to gain transparency could be reducing interdependence between production units, create order, implement visual controls, measurements of the performance, and by making both the process and the instructions directly observable (Koskela 2000; Koskela 1992).

To hinder suboptimization there need to be a focus on both the entire process and on each subprocess. One way to hinder suboptimization is to establish an overview of the complete process and having the complete process process in mind when optimizing the subprocesses. To do this we should according to Koskela (1992) first measure the total process, and secondly implement an authority to control the entire process.

And finally the improvement in every aspect has to be continuous, and has to involve every employee. A tangible improvement can then be gained in small but steady steps (Koskela 1992).

DISCUSSION

In relation to Lean Construction and the T-F-V theory an expanded time frame is positive. Though still one should remember that time is considered as a source to

waste. But could time be necessary waste to achieve improved production? A Removal of the fixed deadline will remove complexity this means less trades on site and more gaps between the interacting activities. Moreover, it will help simplifying the construction process and minimizing variability. This results in a more smooth construction process. Because of simplification waste is easier spotted and removed. By optimizing the work of the individual contractor lead time could be reduced. Finally, more robustness will be put into the schedule, which lowers the needs of buffers.

Even though more time will give a positive effect on production there is still two things which need to be considered. First of all cost has to be considered. An unrealistic tight timeframe will be inflexible. Because of limited slack between activities it will be unable to absorb variability in production. Interdependencies between contractors cause delays and conflicts to be transmitted from one contractor to another. The result is decreased productivity and increased costs. A tight time schedule increases the number of hot spots leading to a more chaotic, complex and uncontrolled construction site. To catch up, the work needs to be even further accelerated resulting in even more hot spots. As shown accelerating work is cost full. This is supported by Thomas (2000) who, as a result of accelerated work, recorded a decreased productivity on 25%. Finally, strict time limits entail the workflow to be optimized under non-optimal conditions. Even though productivity seems to be increasing, productivity per man-hour is decreasing resulting in increased cost.

Still too much time is not necessarily positive, because of a tendency in the industry to work best under pressure. Often extra time is wasted bringing productivity down. Extra time brings extra costs (Bromilow 1969; Walker 1994; Kenley 2001). To avoid extra cost the deadline should be realistic, negotiable and flexibility in both directions.

The timeframe has to be set individually for every construction project where both internal and external costs must be taking into consideration. Therefore, as a general guidance, the timeframe should fit the individual project. But the deadline should be flexible instead of fixed. Negotiations between contractors and client should be in focus in a constant search for win/win situations. An increased focus on collaboration and negotiation between contractor and client will move the construction industry away from contract bonded projects. The results will be: decreased complexity, improved workflow, increased productivity, and increased value creation.

The second thing to mention is value. According to the Lean philosophy we should try to increase customer value. And time is a parameter which affects customer value. Here delays would cause dissatisfaction. This also indicates that the timeframe needs to be realistic. However, according to the interviews, quality is not noticeably affected by a tight schedule. The contractor still has to fulfill the contract. Therefore, (s)he has a fixed quality agreement which may not be compromised when accelerating the work.

The tight schedule also affects the site managers. This sometimes results in too fast and not thought through decisions. This tendency is supported by Wantanakorn et al. (1999). But by involving the contractors who are affected by the decision and collaboratively find a solution most poor decisions are eliminated.

CONCLUSION

Through interviews with site managers and by looking into theory the effects of an extended timeframe was examined. It was found that a too tight schedule leads to conflicts and increased cost, while a too loose schedule often resulted in an unnecessary waste of time which also resulted in increased cost. The conclusion is that the time frame has to be realistic but flexible. Therefore, the time frame needs to be determined individually for every construction project. By introducing flexibility into the timeframe negotiations between contractor and client should help creating win/win situations in the attempt to bring both productivity and value creation up.

By creation win/win situations project cost will decrease. When negotiating win/win situations both internal and external costs should be taking into account. In relation to customer value, it is important that the agreed schedule is realistic and obeyed. Delays and non-met agreements will decrease customer satisfaction and thereby decreasing the value creation.

Finally, the relationship between extra time and the T-F-V theory was considered. In the T-F-V theory time is considered waste. Even though extra time overall might have a positive effect on productivity and cost. Therefore, a more nuanced picture of time is needed. Even though time is waste wisely determined extra time can be necessary waste in the road to excellence in construction. Furthermore, extra time will increase the robustness of the schedule.

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ADDING PRODUCTION VALUE THROUGH APPLICATION OF VALUE BASED SCHEDULING

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ABSTRACT

Customer value is a key goal in the Lean philosophy, essentially only actions that adds value should be conducted. In a transformation view, the basic lean approach is to remove waste, which indirectly increases value (or withstand value lose). Lean Construction acknowledges two different types of value views. Product value, as stated above and value in relation to cooperation in the construction process. Process values are important when it comes to the comfort (physical and mental wellbeing) of the craftsmen cooperating aligned around the same goal of a smooth process and a great end product. By increasing the comfort of the craftsmen their productivity could increase. Furthermore, shared process values decrease the needs of managerial standards, structures, and systems. By means of a questionnaire survey this study investigates the connection between scheduling and the comfort achieved through process values of both engineers and foremen on site. The questionnaire identifies relevant process values, and these are compared to values observed in the scheduling process at three construction cases. The aim is to minimize time usage in the scheduling processes and to increase robustness of the schedule by securing an adherence of the schedule. The results show a lack of focus of the scheduling process' surrounding atmosphere. Process values such as sympathy, kindness, helpfulness, and equality had only minimal attention. In order to foster these "soft" values it was found that hierarchy should be minimized and management should seek towards democratic leadership.

Keywords: Last Planner System, Lean, Scheduling, Values, Waste.

INTRODUCTION

Ohno (1988), one of the fathers to Lean, stated that the total capacity of a production system equals the sum of work and waste. Therefore, in order to increase the work and streamline the production Lean has a partisan focus on removing waste. Lean emphasizes the production as a flow of materials where raw materials are undergoing moving, waiting, inspections, and transformations before it reach the intended shape and function as the final product or construction (Koskela 2000; Koskela 1992). Only transformations add value to the product. All other activities are only expenditures in cost and time and can be regarded as waste. The concept is then to eliminate or

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minimize waste by eliminating the non value-adding activities and streamlining the value-adding activities (Lindhard and Wandhal 2012; Koskela 1992). In order to remove waste you need to know and eliminate the root causes. In Lean theory 7 different sources to waste are identified: 1) Waste of overproduction, 2) Waste of stock on hand, 3) Waste of transportation, 4) Waste of making defective products, 5) Waste of processing itself, 6) Waste of movement, and 7) Waste of time on hand.

Lean, which includes Lean Construction, only focuses on the hard and direct observable waste. In relation to Ohne's definition a production system consists of work and waste. Work is often considered to be only the transformation, because it is the output. But as an input, in order to complete the transformation, human production factors are needed. The motivation and skill of the employees are having a huge impact on the output both regarding quality and quantity. Thus humans can affect the capacity of the production system. This is especially the case in construction which is considered a labor intensive industry.

Improved human skills are expanding the capacity of the production system since new knowledge is added. Opposite does improved motivation not add anything to the existing system. Therefore, improving motivation is an exploitation of capabilities already in the production system and a known approach to minimize waste. Capabilities and utilization is also important in relation to the machines in the production system. Therefore, the phrase can be generalized to: Waste is not to fully utilize of the capabilities and possibilities in the production system.

As mentioned, Lean's primary focus is on removing waste to maximize the value creation. In fact the production outcome is the same, but value loss is evaded by reduced resource usage. Thus removal of waste does not extend the existing value creation in the production system. Extending the value creation can only be achieved by improving the work to increase the customer satisfaction, cf. Ohne's rule.

Creating value is a fulfillment of the customer demand and requirements. Johnson and Kaplan (1987) defined value this way: "*value of any commodity, service, or condition, utilized in production, passed over into the object or product for which the original item was expended and attaches to the result, giving it its value.*" Creation of value in any production system is achieved by producing what the customers want to fulfill the customers' demands and requirements. In construction this value creation has two customers: the next trade and the end customer (Wandahl 2004a). Value creation is measured in relation to cost which includes the consumption of both time and resources. Moreover, value is determined in relation to achieved benefits and compared to value and cost of substituting and competing products.

Creation of value comes through process, but the values in the process are important for maximizing the human input. Production process values are important when it comes to the comfort and motivation of the individual craftsman on site (Bejder et al. 2008). By increasing comfort and motivation of the craftsmen their dedication and accountability will increase resulting in increased productivity (Singh 1996; Olomolaiye 1988). Accountability is important in the scheduling process where the schedule is founded on commitment which needs to be obeyed. Due to interactions and interdependencies between the subcontractors, the flow of work is dependent on fulfillment of these commitments.

The production process values are a part of the corporate culture which dominates the construction site (Van den Steen 2010). Culture is the social and nominative glue that holds the, in construction, temporary organization together (Siehl and Martin 1990). The main organization in construction is a joint of smaller organizations from the participating subcontractors. Thus, there is a hierarchy of culture where the individual subcontractor has its own subculture (Hunter and Tan 2006).

Culture is by Triandis (1972) defined as: *“an individual’s characteristic way of perceiving the man-made parts of one’s environment. It involves the perception of rules, norms, roles, and values, is influenced by various levels of culture such as language, gender, race, religion, place of residence, and occupation, and it influences interpersonal behavior.”* According to Kroeber and Kluckholm (1952), culture is affecting behavior by determining patterned ways of thinking, feeling and reacting. Therefore, since behavior is determined by culture, culture needs to be managed. In construction the overall culture changes since organizations change. Every project consists of its unique composition of organizations and employees which together forms the projects culture. Thus, management of culture is important for ensuring optimal capacity utilization, i.e. optimal output of the production system.

Value Based Scheduling (VBS) is introduced in an attempt to affect behavior through changed culture. The concept is focusing on leadership and the connected process values. The objective is to increase motivation, collaboration, and output by establishing comfort and trust between individual craftsmen. An improved involvement when making commitments in the schedule makes the schedule more realistic. Together with increased accountability and dedication the likelihood for observing the schedule is increased. As mentioned every construction project consists of its own unique culture. Therefore, the values should be determined at project basis to fit the present project. Cultural changes are difficult to accomplish, hence it is important to ensure everyone’s support in this change process. It is therefore critical that everyone is consulted and have a voice when the values are determined. This ensures alignment and observance of values from top management to each craftsman, on site.

VBS is a parallel to Value Based Management, where values constitute a supplementary scheduling, planning and management tool (Wandahl 2004b). VBS is a proactive approach to avoid or limit problems related to scheduling. The values form an ethical guideline supporting on site behavior and support and reduce the demands to the existing scheduling system, which at a Lean construction company would be Last Planner System (LPS). VBS increases the reliability of the schedule, because commitments increasingly are kept. Values affect behavior by increasing motivation, dedication and accountability, resulting in an increased probability of schedule observance. Thus the robustness of the schedule is increased.

It is important that the scheduling system supports the determined values. Therefore, the purpose of this research is to determine which values in general are preferred in such a system. Moreover, this research suggests which values a scheduling system is expected to deliver. By fulfilling the identified values and needs the scheduling processes can be improved. Identification of the values is achieved through the following research question:

Which values could be combined with existing scheduling procedures of onsite construction and how can these values support Last Planner System?

RESEARCH METHODOLOGY

To investigate which values that are preferred in a scheduling process an electronic survey was conducted. The samples in this survey were A) the members of leanconstruction.dk, comprising 16 contractors representing a large proportion of contractors in Denmark B) former students at the MSc in construction management programme at Aalborg University, who present is employed as contractors. The two samples were chosen because respondents, to a greater extent, were expected to know about and have experiences with Lean and LPS. Usage of LPS is important since it is based on Lean thoughts. This increases the quality of the replies and the validity of the survey. In total 192 persons were included in the survey. The questionnaire was completed by: 14 project managers, 17 construction managers, 16 site managers, and 7 foremen. The respondents represent varying opinions and contribute with different experience to scheduling. This secures an unbiased and valid survey.

The questionnaire process takes its outset in the strategy presented in Akintoye and MacLeod (1997). First, an initial invitation was sent out to every participant and after two weeks a reminder was sent out to those who had not yet completed the survey. In total 51 persons completed the survey resulting in a response rate of 27%. In the questionnaire the respondents were asked to rate a number of values in relation to the importance in the scheduling process. The values in the survey were found by reviewing the values represented at a number of partnering projects.

Additional three construction cases were followed see Table 1. At the construction cases LPS had to be applied. Data collection consisted participation in scheduling meetings and observations to capture the production process values. Onsite observations help capturing the context wherein the scheduling is conducted. Focus was on the atmosphere and values which were characteristic at the meetings.

Tabel 1 Data collection at the three case-studies.

	Case 1	Case 2	Case 3
Contract form	Turnkey contractor	Turnkey contractor	Prime contractor
Site observations	Once every fortnight in total 5 observations.	1-2 times every fortnight in total 8 observations.	1-3 times every fortnight in total 8 observations
Meetings participated in	Subcontractor, foremen and safety meetings	Subcontractor and LPS meetings	Subcontractor, foremen, emergency and construction meetings
Observation length	10 weeks	10 weeks	10 weeks
Interviews of site-manager	Unstructured and semi-structured	Unstructured and semi-structured	Unstructured and semi-structured

The research presented is a part of an ongoing research project aiming to disclose new parameters to help and support scheduling in construction. The research is explorative and open minded, and is trying through creativity to avoid the limitations of a narrow-minded and traditional way of thinking.

RESULTS

A questionnaire was designed to capture and rate the importance of different values in relation to scheduling processes and the schedule itself. To capture a complete and nuanced picture project managers, construction managers, site-managers and foremen

has been included in the survey. The results from the questionnaire are afterwards compared with case observations from 3 construction sites. Focus has been on how and whether or not the values are supported, encourage, and fostered in LPS.

In the questionnaire the respondents were asked to rate the importance of certain values and to which extend they found it important that the given values would be supported by the scheduling process. The results, which are presented in Table 2, shows a tendency in the construction industry to rate the “hard” values such as responsibility and collaboration higher than the “soft” values such as helpfulness, kindness, and sympathy.

Table 2 “If scheduling should be combined with values to which extend do you think the schedule should encourage [Value]?” When calculating the weighted average: to a very high degree was valued 1000, a high degree 100, some degree 10, lesser degree 1, and not at all 0.

[Value]	Respondents	Weighted average
Responsibility		643
Respect		534
Cooperation (Willing to share)		530
Honesty		518
Trust		514
Equality		392
Helpfulness		255
Kindness		226
Sympathy		199
Total (N=)	51	

Responsibility turns out to be the highest rated value. Thus it is important that the involved contractors’ respect and obey the mutual agreements and, as best as one can, seek to observe the commitments. Therefore, responsibility is a key issue in LPS in the search for increased robustness. Responsibility is together with trust the only values LPS directly seek to foster. In LPS trust lays the foundation to collaboration.

In LPS, responsibility is increased by involving foremen in the Phase scheduling. Participation and joint-responsibility increases the awareness of subcontractors regarding the importance of observing the schedule. Moreover, responsibility and awareness are fostered by the implemented PPC calculation. Basically, PPC is a measure illustrating the percentage of kept commitments, where also trust and honesty comes to a test in relation to the likelihood of commitments being obeyed. Furthermore, joint-responsibility in the scheduling and sequencing does unite the parties and encourages collaboration.

LPS puts only little attention to the atmosphere wherein the scheduling processes proceeds and to the comfort of the individual craftsmen. This was characteristic at the observed cases where no focus was on kindness, helpfulness, sympathy, equality, or respect. It is important to stress that the “soft” values increase comfort. It was therefore, no surprise that one of the three sites was dominated by a harsh tone. This rough behavior was promoted by the site-manager who had a very brutish appearance. Moreover, he used his hierarchical advantage to force through his own agenda and opinions. His leadership did not at all seek towards equality and did not encourage

collaboration, honesty, sympathy, etc. Hierarchy of power was observed at all three construction sites. But in the other two cases the hierarchy was not as direct visible and not used as a management tool.

DISCUSSION

Both the questionnaire and the studies show that scheduling in today's construction only has minimal focus on the values which foster comfort to the individual employee at site, and hence frames an effective working climate. Management should put more effort into ensuring this comfort because it is the breeding ground for motivation and mutual trust. All too often construction sites are plagued by internal competition among the participating trades. In the worst cases this leads the trades to a state of war where the only objective is to maximize own profit, and to sub-optimize in all aspects. Therefore, Lean could be improved by focusing not only on transformations but also at the leadership which guide and support the transformation process to increase comfort and motivations of project participants. The result will be increased efficiency and productivity as well as a more robust schedule.

Production process values should be identified to support the existing schedule system. Values need to be mutual developed and agreed. This will ensure all subcontractors commitment for observance. Common goals and values lay the foundation for the culture at site. It unites and glues the temporary organization together and makes them act as they were one company, cf. Siehl and Martin (1990). Additional long-term cooperation through partnering or joint ventures could form the setting for a united culture. This will improve the scheduling and the encouragement for collaboration will increase. The willingness to share resources to increase utilization and find common solutions will also be expected to rise.

Finally, it is important to minimize hierarchy of power in the scheduling process. Lean should seek towards a flat organizational structure. Here, it is important that all participants should be involved and have an influence in the development of the schedule. This increases the quality of the schedule (Ballard and Howell 1994). Moreover, it increases the motivation by fostering equality, sympathy, and mutual respect.

Construction sites are often dominated by autocratic leadership which, according to Cassel (2008), creates "*ego-centered*" individuals where competition and power drives the motivation. Mutual competition at construction sites is evident and composes a significant problem in today's construction. Mutual competition was observed multiple times during the case studies, and hindered collaboration. Thus is there a need to change this style of leadership. Construction sites should seek to be managed through democratic leadership. According to Cassel (2008) individuals under democratic leadership tend to be social- and group-centered. Moreover the extreme emphasis placed on competition is replaced by courtesy, honesty, and cooperation (Cassel 2008).

FUTURE RESEARCH

This research is an initial part of an on-going research that emphasises the human aspect of construction production scheduling. Here, VBS is intended as a support to LPS to increase robustness of the schedule by increased motivation and dedication to the commitments. Additional further research is needed to support the research and to

form guidelines for selection and observance of values and how they can be supported by leadership style. Among others this involves pilot projects to test the theory.

CONCLUSION

Lean does not focus on the importance of humans in the production system and ignores their influence on capacity and quality. Humans do together with machinery and equipment compose the production system. Improving motivation is a utilization of the existing capabilities in the system. In Lean, there is no direct focus on utilization. Here, not fully utilization of the capabilities and possibilities in the production system should be regarded as the 8th source to waste.

If utilization is regarded as waste unnecessary waste could be removed if the motivation and comfort at the employees on site is improved. This can be achieved by focusing on the production process values. Moreover, values form an ethical guideline which influences culture and behavior. By fostering dedication and responsibility the likelihood for observing the commitment in the schedule is increased.

The atmosphere wherein the scheduling process proceeds is important to the comfort of the individual participant. Management should increase their effort of ensuring this comfort because it is the breeding ground for motivation and mutual trust. Therefore, leadership is important. Site management should seek towards democratic leadership because it encourages courtesy, honesty, and cooperation which are key elements in an attempt to improve the current scheduling system. In general Lean should seek towards minimal hierarchy because involvement and influence improves the quality of the schedule and it fosters equality, sympathy, and respect.

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DESIGNING FOR SECOND GENERATION VALUE – FUTURE PROOFING CONSTRUCTIONS

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ABSTRACT

Lifecycle consideration in terms of environmental impact and total cost of buildings attract increased focus in construction. Here, total cost and environmental impact both involves: erection, operation, maintenance, demolition, and disposal of the building. The mindset of Lean Construction is focusing on eliminating waste and adding customer value to both the design and build phases. But in this aspect waste and value is only viewed in the first generation owner perspective with fixed usage. Through theoretical considerations this research looks into the change of customer value. Changes happen, so do changes in usage of buildings. Organisations and structures change, the result is often changed requirements or changed value perceptions. Customer value is decreased since the owner has a building not fitting the present demands. Hence, there is a need of a construction redesign or in a worst case scenario the building end up unused. If, in the design process thoughts have been put into the “*value-lifecycle*” including second and even third generation usage, the transformability process of needs from generation to generation could be improved. This way value is kept in the building. Keywords in what could be called Flexible-Value-Design are multiple usage possibilities, flexibility and transformability.

Keywords: Flexibility, Lean Construction, Transformability, Value, Waste.

VALUE CREATION IN CONSTRUCTION

Value is an important element in Lean Construction and design. Here, the basic concept is to remove waste in order to increase the value creation (Freire and Alarcón 2002; Koskela 1996; Koskela 1992). According to the Lean philosophy value is to build what the customer wants or desires. Thus, it is a fulfillment of the customers’ wishes, demands, and requirements. Johnson & Kaplan (1987) defined value this way: “*value of any commodity, service, or condition, utilized in production, passed over into the object or product for which the original item was expended and attaches to the result, giving it its value.*”

The question which needs to be asked is: who is then the customer? In Lean an activity is said to have two different customers (Wandahl 2004). Construction projects

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consist of multiple trades with interacting and interdependent activities (Bertelsen 2003; Salem *et al.* 2006). The first customer is the trade which have to follow up on the completed activity, i.e. the next link in the supply chain. The successor is dependent on the quality of the work and it being ready on time. If the previous activity is not completed or rework is necessary his own work cannot be conducted timely. If he has no buffered activities his productivity will decrease. Furthermore, because the construction is restricted by a tight sequence delays in one activity will easily be transmitted and therefore affect other subsequent activities (Lindhard and Wandahl 2012). The second customer is the end customer, user or the owner of the construction. Here, functionality, design, quality, cost, time, etc. are affecting the end customers' perception of value at the acquisition date.

Value creation is said to be a fulfilment of the customer's needs (Freire and Alarcón 2002). The Lean Construction philosophy seeks increased customer value. But value is only viewed in relation to the 1st generation owner and with fixed usage. Thus, focus is only on capturing and fulfilling the present needs of the owner (Freire and Alarcón 2002). Therefore, only the current needs are in the design process captured and transferred into design specifications (Ballard and Koskela 1998). The owner's present needs represent only a snapshot of the owner's value perception which over a period of time will change (Flint *et al.* 1997). Usage of buildings follows the changing needs of the owner and users and does therefore also changes with time. Therefore, the perception of the buildings value decreases when the building no longer fulfils the owner's needs.

More attention and new approaches is needed in order to overcome the owners changing value perception and preserve the value of the building. Moreover, when designing buildings it must be taken into consideration that the building at some point will change users and even owner. Here, the building now has to fulfill the needs of the new users or the 2nd generation owner. Furthermore, when the building is put up for sale the transferability is important, and together with the market value it composes a large share of the owner's value perception of the building.

In order to preserve the value of the building the buildings fulfillment of need has to be flexible making it possible to adjust for future needs. Therefore, when designing and constructing with multiple usage possibilities in mind much more value can be added to the building. Furthermore, to future proof the construction, 2nd and 3rd generation owner value should also be considered to increase the buildings value in the whole lifecycle.

A CHANGING ENVIRONMENT

The world is not static but dynamic and changing. Companies and cities develop through time and causing the surrounding environment to change. The developing companies have continuously to make organizational, infrastructural, and constructional changes to adjust and fit into the new reality (Simons 1994). Still constructions are when designed and constructed viewed as static monuments.

The companies changing constructional needs lead to redesigned, sold, or in worst case unused or demolished constructions. Thus, sold constructions do reflect the tendency of changes in the owners' value perception and needs. Historical evidence show that the usage of constructions change. Therefore, in an attempt to picture the changes in usage of construction the national statistic of registered sales in Denmark

is shown in Table 1. The figures have to be related to the number of inhabitants. Denmark is a small country with approximately 5.4 million residents.

Table 1 Registered Sales in Denmark (DST 2012)

Sales: Year	2006	2007	2008	2009	2010
Factories and warehouse buildings	1.756	1.617	1.219	705	1.240
Agricultural property	5.498	5.598	4.782	3.556	3.595
Business property	2.069	2.061	1.545	1.006	1.289
Mixed residential and business property	3.448	3.122	2.306	1.538	1.799
Apartment block	3.765	3.526	2.476	1.738	2.333
Single-family homes	58.950	58.270	46.138	40.551	46.504
Owner-occupied flats	22.098	20.834	15.567	13.540	15.943
Holiday homes	11.412	9.858	7.522	7.000	8.020

From Table 1 the total business related sales can be calculated. This includes factories and warehouse buildings, agricultural property, business property, and mixed residential and business property. From 2006 to 2009 the total business related sales varied from 6.805 to 12.771 sales. During the financial crisis the sales dropped down.

Despite a concomitant changing effect which was expected to raise sales the crises did moreover affect the companies' solidity and the propensity to invest. Furthermore, the crisis did make it difficult to receive mortgage loan. This made the property difficult to sell and the prices dropped (Brunnermeier 2008). Therefore, a lot of companies' have been forced to keep constructional facilities which do not fit the current needs. To keep the construction still useful transformability and flexibility has been extremely important.

Not only big financial crises affect the owners' constructional needs. Small changes or developments in the surrounding world continuously change the owner's value perception. Changes happen both inside and outside the company and forces changes to the constructional needs. Everything can change and affect the usage of the construction. Thus, changes are influenced by an infinite number of parameters which make the changes complex and impossible to forecast.

Changes in the organization will always induce changes in usage of the constructional facilities. The owner can choose to ignore these changes by accepting a reduced fulfillment of needs, he can choose to redesign the construction to fit current needs or he can choose to sell the constructions where after the 2nd generation owner has to redesign the construction to fulfill his needs. To fit the building to the new demands the building has to go through a transformation process.

Transformability is important. Multiple options promote the likelihood of a redesign of the constructions. If the construction is not transformable it is a risk that it sometimes in its lifecycle will end up unused or demolished before necessary. The key is to design the building so the transformation has to be as little and as simple as

possible. Thus should changes be as quick, easy, and cheap to complete as possible. To promote transformability the building needs to be designed for a changing environment. Thus, the design process should consider the whole “*value-lifecycle*” of the construction which has to fulfil the changing needs of both 1st 2nd and 3rd generation owners. The question which needs to be answered is:

How do we handle the changing needs of the customers and how can we increase the constructional transformability to make the constructions fit to current needs?

The research is explorative, open-minded, and visionary; it tries through creativity to avoid the limitations of a narrow-minded and traditional way of thinking. The research presented is grounded on theoretical considerations alone but will be followed and supported by further research. The future research will focus on the changing constructional needs of companies in Denmark.

HANDLING CHANGES IN USAGE

Companies are continuously affected by their surrounded environment which changes their needs and value perceptions. Often these changes are related in the marked and therefore difficult to forecast. The outcome is changed usage of the company’s constructional facilities. It is important to secure that the building is fully utilized and still fulfil the company’s needs. Therefore, to enable the company to respond to changes, constructions need to be adaptable.

Even though changes in general are difficult to forecast some changes might be predicted and should be considered already in the constructions design face. Many future problems can be caught before emerging by carefully contemplate the construction design. Tendencies in the surrounding environment and the existing marked can be analysed and predicted just as in real business life.

Foresight is important. Here, the company’s plans and expectations to the future are in particular important. For instance, it would be stupid to build a construction with a non-expandable max capacity if the company is experiencing or expecting high growth. One way to capture the future needs could be by making the owner conduct a “*lifecycle*” plan of his expectations to the future usage of the building in its lifetime. Thus, the design face should proceed based on the owner’s “*lifecycle*” plan. Predicting the future is difficult. Therefore, it is important to notice that the “*lifecycle*” plan is only expectations which thus are not necessarily fulfilled.

In order to optimize the value-fulfilment the “*lifecycle*” plan needs to cover all relevant focus areas. One example to a focus area to carefully consider is the location. A lot of factors have to be taken into consideration. For instance: Does the location fulfil potential future needs? Does the location make it possible to upgrade and expand the facilities? If a future expansion is considered should surrounding acreage be purchase? How do geographical changes in the marked and organizational changes in the company affect the location? How is the location in relation to transport options and logistics and can the location fulfill potential future needs with increased sales? Is it possible to attract a qualified labour force? If a future sale is necessary would the location promote a future sale? All relevant questions need to be answered and considered already when the construction is designed.

There are a lot of other relevant focus areas besides the location. Another example could for instance be environmental concerns including future environmental requirements, energy consumption, and the company's external appearance as an environmentally preferable company. It is important to state that the list is not considered exhausting. The number of questions and consideration continue almost infinitely. If all concerns have to be considered the design process will become very complex and cost full. Therefore, the purpose with the "lifecycle" plan is to let the company identify the relevant key issues. These key issues do then form the groundwork to the subsequent design of the construction.

Furthermore, since plans does not always become reality the contemplate design with relation to the owners "lifecycle" plan should be supplemented with an increased flexibility and transformability in the construction design.

Flexibility is understood as the ability to change the constructional usage without needing to make constructional changes. Thus, increased flexibility makes the construction agile because the ability to adapt to the changing environment is increased. The key to flexibility is design the construction with multiple applications in mind. This could for instance be by making the inner shape of the room flexible. This could be achieved by using walls or interior which are easy to displace.

Constructional flexibility would make it less cost full to change the design since it reduces the need of transformation in the adaption process. But instead will the creation of flexibility in the construction most likely induce increased cost to the erection of the construction. Therefore, both related expenses in cost and time and possible savings have to be taking into consideration in the design face. Therefore, every initiative, which purpose is to increase the flexibility of the construction, has to be considered individually with the owner as the decision-maker.

Transformability is the ability to change usage of the constructional facilities. Opposite flexibility the construction is transformed in the process. The constructions transformability is determined in relation to the cost, time, and the resources spend in the transformation process. Basically there are two different types of transformability. Here, one type of transformability is related to the ability to transform the existing structure in order to adapt to the changing environment.

One approach to achieve transformability in the existing structure could be by reducing the number of load-bearing wall which penetrate the inner structures. This increases the adaptability in the inner design of the construction where light wall easily can be broken down or dissembled.

The second type of transformability is related to the ability to ad structures to the existing structure. This form of transformability could for instance be related to the possibility to add an extra floor to an existing construction, building an expansion, or constructing an entire new structure. Since this transformation has to be completed without ruining the design of the constructions both design and structural concerns are critical. Since increasing the transformability of the constructional structures, likewise flexibility, is cost full a cost-benefit analysis needs to be preformed. Again the initiatives have to be considered individually where it in the end is the owner's call to make the final decision.

It is important to notice that the effects of value changes are not limited to be handled in design. Changed values and needs can have an impact already in the construction phase. Often the owner does, in collaboration with the architects, continuously make changes in the design. This is often small changes related to materials, textures, or colors but sometimes the changes are having a greater impact even at the structural design. Therefore, construction planning and scheduling does not only have to cope with the complexity and changing nature of a construction site it also has to be able to handle the owners changing needs satisfactorily. Changed design caused by changed owner values or needs bring uncertainty into the schedule. The scheduling tool needs to be able to handle this uncertainty and still keep a steady workflow to maintain high productivity.

Today most changes evolve unforeseen. Changes can happen at any time and therefore interrupts the making ready process. To minimize the impact changes has to be foreseen. One approach is to investigate the triggers which cause changes. This helps site-managers to understand and predict future changes. A second approach to foresee upcoming changes and react faster is to improve the communication between construction site and owner and architect. If structural changes are needed the flexibility and transformability of the construction is once again important to adjust the construction to fit current customer needs. Moreover, the flexibility and adaptability is important in the workforce and in construction process itself. Communication and collaboration are essential when handling changes. It takes teamwork to work around the changes to find and exploit new possibility and to optimize the process. Furthermore, communication and collaboration does minimize misunderstandings.

FUTURE RESEACH

This research is an initial part of an on-going research that emphasises Lean Construction and creation of customer value. The main focus is on how to coop with changes in the customer's value perception in relation to usage of the constructional facilities in the constructions lifetime. The purpose of this research is to create a broader understanding of values not as static but dynamic. Additional further research is needed to support the research and to form guidelines for achieving flexibility and transformability in the design face.

Future research areas include:

- What are the root causes to why companies replace or redesign the constructional facilities.
- Understanding the dynamics which drives and triggers changes.
- How constructions are adapted to the changing environment and which parameters do increase this transformability.
- How flexibility and transformability can be achieved in an constructions
- What are the key parameters which should be considered in order to future proof a construction.
- How and when foresight is achieved.
- Improving the schedule in handling unexpected changes

CONCLUSION

In relation to the Lean Construction philosophy value is achieved by fulfilling customer needs. To respond on a changing environment constructional usage needs to adapt to respond to the changing world and fit to the present needs. Even so constructional value is in design considered as static. Thus, the design process should consider the whole “*value-lifecycle*” of the construction which has to fulfil the changing needs of both 1st 2nd and 3rd generation owners.

In order to preserve the value in the construction the constructions fulfillment of needs have to be flexible making it possible to adjust for future needs. Changes are difficult to forecast but instead of ignoring the changes tendencies in the surrounding environment and the existing marked can be analysed and predicted. The company’s plans and expectations to the future are in particular important. Therefore, it is suggested that the owner should conduct a “*lifecycle*” plan of his expectations to the future. Thus, the design face should proceed taking the owner’s “*lifecycle*” plan into consideration.

Since forecast not always are reliable the construction still needs a flexible and transformable design to increase the adaptability to changes in usage. Flexibility is understood as the ability to change the constructional usage without needing to make constructional changes while transformability is understood as the ability to change usage of the constructional facilities by transforming the constructions. The constructions flexibility and transformability is determined in relation to the cost, time, and the resources spend in the adaption process.

Transformability can be categorized into the ability to transform the existing structure and the ability to ad structures to the existing structure. Since transformation has to be completed without ruining the design of the constructions both design and structural concerns are critical. Opposite is constructional flexibility achieved by designing the construction with multiple applications in mind.

Increasing constructional flexibility and transformability, to make the construction agile to changing usage, is cost full. Therefore, both related expenses in cost and time and possible savings have to be taking into consideration. Every initiative, which purpose is to increase the flexibility or transformability of the construction, has to be considered individually with the owner as the decision-maker.

The tendency of changes in customer needs is often already experienced during the construction phase where the schedule has to handle the unexpected changes in the design satisfactorily. If a change requires structural changes flexibility and transformability of the construction is once again important. The impact of changes can be reduced by understanding the triggers to predict future changes. Furthermore, the impact can be reduced by improved communication and collaboration at site.

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ON THE ROAD TO IMPROVED SCHEDULING – FITTING ACTIVITIES TO CAPACITY

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ABSTRACT

Last Planner System has through the sounding process increased the reliability of the schedule. The sound activities are moved to a buffer and afterwards selected to the Weekly Work Plans to match capacity. Therefore, in order to maximise productivity it is essential to ensure that the sounding process proceeds in a pace which ensures that enough activities are made ready to the Weekly Work Plans. Experiences from case studies are included. It is observed that site-mangers tend to either include at risk activities or to adjust the manning in order to mach work with capacity. Several different solutions to the problem are suggested and discussed. It is proposed to simplify the production by decreasing the number of trades and tasks completed at site. This can be achieved by increasing prefabrication, preassembly and modularization. If congestions in the making ready process occur buffers should be introduced to absorb the effect. This is achieved by introducing slack at the critical path and supplementing it with buffers of “time” flexible activities.

Keywords: Buffering, Flexibility, Last Planner System, Lean Construction, Scheduling.

INTRODUCTION

Improvement of production processes is often measured through productivity increase. Such statistical measures enable comparative analysis of different production conditions. Construction is often compared to traditional manufacturing, and several studies have provided statistical evidence for construction lacking behind the productivity development of traditional manufacturing (Bertelsen 2004; Winch 1998). This despite recently enhanced focus on improving the productivity of onsite production in construction. Efforts range widely, but this research follows the tail of Ballard (1999) who found that the amount of non-productive time in onsite production amounts to 50% of the total construction time. Thus Ballard’s study only addressed non-productive time related to rework and delays. The indication is clear there is a large potential for productivity improvement in onsite construction.

The Lean Construction philosophy originated in a quest to increase productivity in the construction industry (Liu *et al.* 2011). The first step into developing the lean tool

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Last Planner System (LPS) was taken when Howell and Ballard through a field study found that only half of the assignments in onsite construction were conducted as scheduled (Ballard 1999; Howell and Ballard 1995).

LPS consists of four main schedules (Cho and Ballard 2011; Salem *et al.* 2005). 1) The Master schedule which cover the entire construction process and establishes overview by including important milestones. 2) The Phase schedule which, between milestones, optimize the sequence of the different phases of the construction project. 3) The Look-ahead plan contains a making ready window from the Master schedule. In the Look-ahead window future activities are made ready for conduction. When ready, the activities are afterwards moved to a buffer of sound activities. Having a buffer of ready work improves the ability to respond to unforeseen events without affecting productivity (Ballard and Howell 1995; Koskela 1992). To ensure that ready work match capacity there should be at least a 14 day buffer of sound activities (Ballard 2000). 4) The Weekly Work plan is a one week plan of containing the activities which will be conducted. The plan is based on mutual commitments between the subcontractors. In the Weekly Work plan, activities are matched to capacity, and only sound activities from the buffer can be signed to the weekly Work plan (Ballard 2000). Securing that only sound activities end up in the Weekly Work plans increases the success rate of completed tasks and stabilizes the workflow (Ballard and Howell 1995). Finally, the quality of the schedule is measured through the PPC measurement. The PPC measurement serves as a feedback- and learning system. If low PPC is measured root causes are investigated and eliminated in order to increase productivity (Lindhard and Wandahl 2012b).

Making activities ready for conduction

Look-ahead planning is the backbone in LPS and it is the key element to ensure reliability in the schedule. Increased reliability is achieved through the making ready process where uncertainties in upcoming activities are sought reduced (Ballard 1999).

Activities are made ready by removing constraints. Traditionally the Lean Construction theory divides the constraints into seven main categories, known as ‘the seven preconditions of construction’. An activity can only be conducted if these seven preconditions are fulfilled (Koskela 1999). Hence, if one of the seven preconditions is not fulfilled the activity cannot be conducted and productivity will decrease. The seven categories of preconditions are:

1. Construction design; correct plans, drafts and specifications are present
2. Components and materials are present
3. Workers are present
4. Equipment and machinery are present
5. Sufficient space so that the task can be executed.
6. Connecting works, previous activities must be completed
7. External conditions must be in order.

Recently research has proposed to split “external conditions” into 3 categories (Lindhard and Wandahl 2012a). Currently the “external conditions” category covers several fundamentally different subcategories. Putting a name on the specific subcategories brings increased awareness and attention to the preconditions. This helps the site-manager not to overlook any remaining constraints. The “external conditions” category was divided into the following:

- 7a. Climate conditions must be acceptable. The preconditions focus on external environmental effects such as rain, snow, wind, heat, cold etc.
- 7b. Safe working conditions must be present. The national “Health and Safety at Work Act” has to be obeyed to keep the employees safe.
- 7c. The surrounding conditions must be known. The precondition focus on securing that existing conditions, if necessary, are examined. Problems often arise during excavations or refurbishment assignments.

The making ready process is a continuous endeavour. To avoid congestions and to secure a constant flow there is a constant need for ready activities to feed the Weekly Work Plan. If the making ready process is progressing to slow in relation to the schedule the capacity will exceed the ready work resulting in delays and decreased productivity. Construction production is often organized in multiple trades with interacting and overlapping activities which have to be completed in the right sequence (Bertelsen 2003; Salem *et al.* 2006). Therefore, in order to provide the individual trade with sound work the scheduled activities needs to be ready. This makes the making ready process both complex and vulnerable. The complexity in fitting activities to capacity is examined through the following research question:

How can the complexity of the making ready process be decreased in order to fit activities to capacity to create a (continuous and) resistant workflow?

The research aim is to minimize and optimize the handling of misfits between the input from the making ready process and the capacity. The output will be a better workflow which results in increased productivity at site.

RESEARCH METHODOLOGY

Three construction cases were followed in order to observe the making ready process in onsite construction. Here, the focus was to observe arisen problems, their effect on production, and how they were handled.

Some selection criteria were applied in the selection of cases. Firstly, LPS should be used on the case. Phone conversations and mail correspondences with company consultants and site managers were used to ensure this. Secondly, it was a criterion that the contractor, as minimum, was a prime contractor with associating subcontractors. This secured a certain influence to and complexity of the making ready process. These selection criteria were added to increase the validity of the research.

The research was conducted as a qualitative research, where archives, observations, and unstructured interviews were used to collect data from the cases. By using a qualitative approach the making ready process is viewed in its context. The context is important because it affects the process and behavior at the construction site (Hartley 2004). This is supported by Yin (2003) who states that qualitative research is the only approach to answer how and why questions. Data collection from the three cases is listed in Table 1.

Table 1 Data collection at the three case-studies

	Case 1	Case 2	Case 3
Contract form	Turnkey contractor	Turnkey contractor	Prime contractor
Site observations	Once every fortnight in total 5 observations.	1-2 times every fortnight in total 8 observations.	1-3 times every fortnight in total 8 observations
Meetings participated in	Subcontractor, foremen and safety meetings	Subcontractor and LPS meetings	Subcontractor, foremen, emergency and construction meetings
Observation length	10 weeks	10 weeks	10 weeks

EMPERICAL EVIDENCE

First of all it was observed that LPS was implemented differently in all three cases. This in terms of the theoretical correctness and completeness of the scheduling system. In all cases only part of the LPS system were applied. The main observations regarding the application of LPS are summarized in Table 2.

Tabel 2 Application of the making ready mechanisms in LPS.

General observations	
Look-ahead planning	Applied in all three construction cases, but in one case the making ready process had no attention. In one case constraints were dicussed in plenum. Finally, in one case soundness was tracked and constraints were removed using the 7 preconditions as a guideline.
Partisipation in the scheduling process	In two cases subcontractors and formens were directly included in the scheduling process, while in one case the schedule was conducted by management whereafter the subcontractors and formen could make comments.
Making activities ready	Responsibility was delegated to the responsible subcontractor.
The role of Site managment	Site management did not support or guide in the application of the making ready process. Furthermore, the progress and buffer status was not followed
Status of the making ready process	Random problems with the making ready process were observed. Here, scheduled activities could not be conducted because they were not, in time, made ready for conduction.
Responce to variation in the making ready process	A) Adding constraint activities to the Weekly Work Plan to match capacity. This was done with the hope that the constraints would be removed before the conduction started. B) Adjusting the manning of the individual subcontractor to fit capacity to ready work. Changing the manning is expensive it changes the sequence and slows down the production and is therefore a source to delay.

Delegating the making ready progress to the subcontractors entail that the efficiency of the process is left in the hands of the subcontractors. Since site management does not guide or support the subcontractors in the making ready process the likelihood for misusage is increased. If the making ready process is not applied correctly there is no guarantee that only sound activities end up in the Weekly Work plans. Thereby, unreliability has entered the schedule and productivity will decrease.

In all three construction cases congestions emerged between the making ready process and the Weekly Work Plans. The making ready process could not keep pace with the schedule and therefore could not feed the Weekly Work Plans. Even though the making ready process was applied differently there was no noticeable difference in the number of congestions. Moreover, because the making ready was not followed non-completions were difficult to predict and the effect was often unnecessary transmitted to interacting work activities.

Finally, the making ready process is tormented by changing soundness in the ready work activities, due to variation in the fulfilment of the preconditions. Hence it is important to notice that soundness is not a static condition. Varying soundness in ready work can occur in the workable backlog and in activities moved to the Weekly Work Plans. This introduces the risk that an activity in the Weekly Work Plans not is sound on the scheduled time for conduction.

DISCUSSION

From the three case studies it can be concluded that onsite production experience problems with feeding the Weekly Work Plans with ready work. The observations did reveal a tendency only to react after the problem occurs focusing on minimizing the effect. In order to improve the making ready process, root causes needs to be addressed in an attempt to prevent reoccurrences. In the following will different approaches to improve the making ready process will be discussed.

One approach to avoid congestions in the making ready process would be by reducing the number of task conducted at site. Prefabrication, preassembly and modularization are all concepts with that in mind. Simplifying the process is another method to reduce waste (Hopp *et al.* 1990; Koskela 1992). According to Koskela (1992) *“the very complexity of a product or process increases the costs beyond the sum of the costs of individual parts or steps.”* By reducing the number of tasks and keeping the production simple the interactions and interdependencies between the subcontractors are decreased. This provides overview and increases the transparency of the process and makes the project easier to schedule.

Simplification can also be achieved by reducing the number of trades working at site. Again the number of interactions and interdependencies between the subcontractors will be reduced. Reducing the number of trades could be achieved by increased prefabrication, preassembly and modularization. Since it is the subcontractors' responsibility to make work ready, the process will now be affected by fewer variables and dependencies reducing the risk and effect of non-ready activities. Ideologically modularization will simplify the assembly process at site leading to less specialized craftsmen. Less specialization equals more flexibility and adaptability in the assembly process. Moreover, less specialization could reduce the number of trades resulting in more work to the remaining subcontractors. The subcontractors are able to faster react on changes and make adjustments, to fit the ready work activities, without just changing the manning. If to specialized the subcontractors are depending on the soundness of a specific activity. Thus with more work on site not ready activities can more easily be replaced by ready work from buffers.

Another approach to avoid congestions in the making ready process is by increasing flexibility of the tasks in the schedule. An increased flexibility loosens the linkages and interdependencies between the subcontractors. Moreover it gives an increased

productivity, reliability, and it improves the ability to respond on unforeseen events (Ballard and Howell 1995; Koskela 1992).

In general activities in the sequence can be divided into flexible and inflexible work tasks. The free and flexible activities can be used as buffer activities to handle variation without affecting the production. While constraints from the physical relationship between construction components, trade interactions, path interference, and code regulations hinder movement in the inflexible task and tie them to the sequence (Echeverry *et al.* 1991). But even on the critical path slack between activities can be used to absorb small variations. If these variations is not absorbed the productivity will decrease (Tommelein *et al.* 1999).

Another way to increase the flexibility of the production is to increase the flexibility of the workforce. This could be by using multi-skilled crews to make the crews cover a larger variety of work tasks. This way interactions and interdependencies, between crews, could be removed. Furthermore, overtime could be used as a last resort to absorb unexpected delays in activities on the critical path.

Finally, flexibility can be achieved by applying buffers. Since traditional buffering is expensive it is important not to over-buffer but to keep the buffer size adequate and fitting to current uncertainty. If enough work not is made ready the buffered activities will fill up the empty space and keep the production running. This way buffering absorbs variation in the production as well as in the making ready process and increases the robustness of the schedule. If uncertainty and variability is decreased so is the need of buffering. Thus a simplified and more flexible production will reduce the need of buffering.

In addition to traditional buffers where the backlog consists of the following work activities the backlog should be supplemented with flexible activities. These activities can be conducted without regarding the sequencing. Therefore, they have no bindings and can be “stored” until needed. Since preconditions can vary it is important to check-up on the soundness of buffered activities. A weekly “health check” of all activities could be implemented in order to prevent not-sound activities to emerge in the buffer as well as in the Weekly Work Plans.

The ability to convert the production from one task to another is called adaptability. When applying buffers it is important that the switch from the scheduled to the buffered activity is as fast and smooth as possible. By minimizing the time to adapt waste surfacing as non-productive time is removed. In a changing environment such as onsite production where changes is an everyday experience the ability to adapt is crucial. An increased adaptability improves the ability to respond on unforeseen events. This way adaptability is strongly connected to flexibility.

The key rule when avoiding congestions in the making ready process is that activities should always be fit to capacity and not capacity to activities. Therefore, lowering the manning will slow down the production and should therefore only be used as a resort if capacity decreases. To achieve the synergy all the proposed approaches should be used in a combination and fit to the individual construction project.

CONCLUSION

Today changing manning seems to be the solution to handle congestions in the making ready process. Varying the manning is not ideal since it slowdowns the

production which result in delays. Ideally problems should be caught at the root. Therefore, in order to avoid congestions in the making ready process it is recommended to focus on simplifying the production by minimizing both tasks and trades at the construction site. Keeping the production simple reduces the number of interactions and interdependencies between the different subcontractors which makes the construction project easier to schedule.

In spite of all precaution error will occur. Therefore, in order to minimize the effect on productivity of such occurrences actions must be taken. Two different approaches are suggested to absorb the variation: increased flexibility and buffering. An increased flexibility loosens the linkages and interdependencies between the subcontractors and improves the ability to respond on unforeseen events. It is suggested to increase flexibility by introducing slack between activities on the critical path. Slack is used to absorb critical variations in productivity.

Moreover it is suggested to use buffers to achieve flexibility in the production. Here traditional inflexible buffer activities in the workable backlog should be supplemented with flexible buffer activities. Flexible buffer activities are activities which not are tied to the schedule. Finally, it is stated that in order to minimize waste more focus is needed on the adaptability to makes this process as efficient and smooth as possible.

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EXPLORATION OF THE REASONS FOR NON-COMPLETIONS IN CONSTRUCTION

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Abstract:

Construction sites are dominated by chaos and complexity which make the schedule unreliable and difficult to observe. The result is a high number of non-completions in the scheduled activities, which make the schedule unreliable. Last Planner System (LPS) was introduced to increase the reliability. By focusing on the removal of constraints, LPS has successfully decreased the number of non-completions. To further decrease non-completions, this research investigates causes for non-completions at three construction cases. In total 5424 scheduled activities were followed, whereof 1450 ended as non-completions. The non-completions were besides unknown categorized into 11 different groups and a statistical test of means was performed. The research revealed six high-frequent non-completion causes: connecting work, change in work plans, workforce, external conditions, material, and construction design. Furthermore, the study revealed five low-frequent non-completion causes: space, equipment, rework, unexpected conditions, and safety. The results can be used as guidance on where to intervene.

Keywords:

Constraints, Last Planner System, Lean Construction, Preconditions, Scheduling

1 INTRODUCTION

Last Planner System (LPS) is developed in an attempt to increase the reliability of the schedule and moreover the productivity at construction sites. The need for an improved schedule was exposed in a case study conducted by Howell and Ballard (1995). They find that only approximately half of the assignments in a schedule are conducted as planned (Ballard 1999; Howell and Ballard 1995). Further, a study by Howell and Ballard validates the results, and shows that only 35-65 Per cent of the Planned activities are Completed (PPC) as scheduled (Ballard and Howell 1998; Ballard 1997).

LPS consists of four primary schedules: 1) The Master Schedule containing milestones, 2) The Phase Schedule which secures the right sequence of the work, 3) The Look-ahead Plan where activities are made ready for conduction, and 4) The Weekly Work Plans containing the subcontractors' commitments to which activities are to be completed the upcoming week. To secure reliability of the schedule only activities made ready for work are selected

(Lindhard and Wandahl 2012a; Lindhard and Wandahl 2012c) Finally, LPS contains the PPC measurement which is a feedback and learning system. Here, root causes for non-completed activities are investigated and afterwards eliminated (Lindhard and Wandahl 2012c).

The purpose of the Look-ahead Plan is to increase the reliability of the schedule. Look-ahead planning is conducted as a drop-out plan from the Master Plan, containing a span between 3-12 weeks. Each week the planning window slides one week forward (Ballard 2000). The size of the Look-ahead Window depends on the necessary duration of the making-ready process, the reliability of the plans, and project characteristics (Ballard 2000).

In the Look-ahead Window the making-ready process proceeds. Through this constraints are removed to secure the soundness of each activity. Only sound activities are afterwards selected to the Weekly Work Plan (Hamzeh *et al.* 2008; Steyn 2001; Ballard 2000). This increases the success rate of completed tasks, which means that the PPC level increases (Jang and Kim 2008; Ballard 1997; Ballard and Howell 1994).

To secure soundness, constraints have to be removed to avoid non-completions. As a side mark in a research study presented by Koskela (1999) it is found that soundness depends on seven preconditions. If just one precondition is not fulfilled the activity cannot be conducted. Therefore, it is extremely important that assignments do not miss any of the seven input. The seven preconditions are as following:

1. Construction design; correct plans, drafts and specifications are present
2. Components and materials are present
3. Workers are present
4. Equipment and machinery are present
5. Sufficient space to execute the task
6. Connecting works, previous activities must be completed
7. External conditions must be in order.

In a later study conducted by Lindhard and Wandahl (2012b) the preconditions are expanded by splitting “external conditions” into three categories ending up with nine key categories. The “external conditions” category covers several fundamentally different subcategories. Putting a name on the specific subcategories brings increased awareness and attention to the preconditions. This helps the site-manager to trace any remaining constraints. External conditions are divided into the following:

7. Climate conditions must be acceptable.
The preconditions focus on external environmental effects such as rain, snow, wind, heat, cold etc.
8. Safe working conditions must be present.
The precondition secures that the national “Health and Safety at Work Act” is obeyed keeping the employees safe.

9. The surrounding conditions must be known.

The precondition focus on securing that existing conditions, if necessary, are examined. Problems often arise during excavations or refurbishment assignments.

The implementation of LPS has been proven successful. Several case studies indicate that by implementing LPS an increased project performance is archived. Furthermore, improvements have been reported in plan reliability, project delivery time, and labor productivity (Alsehaimi *et al.* 2009; Formoso and Moura 2009; Friblick *et al.* 2009; Alarcón *et al.* 2005; Ballard 2000; Garza, Jesus M. de la and Leong 2000; Ballard 1999).

Even though high PPC has been gained after implementing LPS, a more reliable and robust schedule is still needed (Ballard 2000). Implementation of LPS has been successful in raising PPC to the 70% level. But the PPC level is right now stuck at the 70% level. In order to reach the 90% level or higher, additional actions are required (Lindhard and Wandahl 2011; Ballard 2000; Ballard 1999).

To help site management in reaching a higher PPC level, it is important to understand what causes the non-completion of activities. This can be done by looking into the causes of non-completion. Based on failure rates it can be determined where and how to intervene to prevent non-completions from recurring. In other terms, in the search of continuous improvement, this research aims to disclose root causes and to learn from mistakes through case studies. The research question is:

What are the reasons for non-completion of activities in construction?

2 RESEARCH METHOD

The research question is examined through multiple case studies. Three construction sites were followed focusing on observing reasons for non-completed activities. The number of cases is considered to give “theoretical saturation” (Eisenhardt 1989; Romano 1989). A clear focus is in particular important when conducting case-studies. With a clear research focus you secure to have the right data and avoid collecting overwhelming volumes of data (Eisenhardt 1989). Therefore, Mintzberg (1979) states *"No matter how small our sample or what our interest, we have always tried to go into organizations with a well-defined focus - to collect specific kinds of data systematically."*

The research was conducted as a triangulation of a qualitative and quantitative research approach. An advantage of using a qualitative approach is that the study is viewed in relation to its context (Yin 2003). By understanding the context an underlying appreciation of the problem is gained. Furthermore, processes are influenced by the surrounding context (Hartley 2004). In every case multiple observations are collected, this result in a qualitative data collection. The quantitative approach secures a statistical validity of the collected data. Data is collected mainly through archives and contains summaries from LPS meetings, and actual

meeting participation. At the LPS meetings the scheduling processes and PPC calculation took place. Here, reasons for non-completion were continuously collected.

Two basic requirements were determined when selecting the cases. Last Planner had to be implemented, and PPC calculation had to be conducted. Because data was collected mainly from achieved summaries, it was required that reasons for non-completion or non sound activities were collected and described. To secure consistency the site manager was the same person on all three construction projects. In the selection process, mail correspondences and phone conversations with company consultants and site managers secured the fulfillment of the requirements.

The three case-studies were based on guidelines presented in Eisenhardt (1989). Data from the entire construction period was collected from archives. Additionally, the archive data was in one construction case supplemented with on-site observation, meeting participation, and semi and unstructured interviews with the site manager. Since all cases had the same site manager in charge, insight in the scheduling process from all projects was achieved. Data collected from the three cases is listed in Table 1 which is followed by a short case description.

Table 1. Data collected from the three case-studies.

	Case 1	Case 2	Case 3
Contract form	Turnkey contractor	Turnkey contractor	General contractor
Project followed	Entire construction period	23 weeks	Entire construction period
From archives	Reports from LPS meetings	Reports from LPS meetings	Reports from LPS meetings
Construction period	65 weeks	23 weeks	60 weeks
Activities registered	2239 activities	593 activities	2592 activities
Non-competions	746 activities	134 activities	570
Average PPC	66.7 %	77.4 %	78.0 %

2.1 Case I – Educational institution

Case one was construction of an educational institution. The project consisted of two buildings, in total 11000 m². The main building was a three-storey building plus basement, in total 8000 m², while the secondary building was a two-storey building with no basement, in total 3000 m². In total the contract value for both buildings was estimated to \$29.11 million. Furthermore, the construction period was restricted to only 16 months.

2.2 Case II – Educational institution

Case two was a renovation project of an educational institution involving only renewal of the roofing. As the renovation progressed extra work was added to the original project. Additional work was accumulated to renovation of windows, inner walls, and sewers. In total the project contract value ended at \$4.88 million, with a fixed schedule of 9 months.

2.3 Case III – Housing

Case three was a renovation project of nine residential apartment blocks. The blocks contained a total of 300 flats distributed on 32 stairways. Because of variation in storeys and size, the flats were irregular distributed between the blocks. The contract included renovation of facade and renewal of the roofing. The project contract value was \$28.62 million, with a duration fixed on 25 months.

3 RESULTS

Three construction cases were followed to detect causes to non-completions in onsite construction. In total 5424 activities were registered of which 1450 were not completed according to schedule. In total the 1450 activities revealed 11 different causes to non-completions. However, in 612 of the cases the cause could not be detected. This is a consequence of the study approach, where the data mainly is derived from summaries from scheduling meetings. In 612 incidents the registration was insufficient. The results are presented in Table 2 where the three cases are compared. In the first column the actual registrations are stated, while the second column contains the registration of incidents per 100 planned activities. This calculation makes a comparison between the results possible.

The results are, besides the “unknown” category, divided into 11 categories. The “unknown” category contains non-completions where the reasons have not been identified. From participating in the scheduling meetings, it is expected that some of the unknown registrations are caused by bad scheduling. Here, poor estimates of the duration make it impossible to finish the activity on schedule. Nine categories are non-completions caused by not-ready activities which cannot be completed. These nine categories correspond to the preconditions presented earlier. The remaining two categories contain non-completions caused by changes made in the schedule or activities where rework is required.

A quick glance at Table 2 shows similarities in the results from case to case, i.e. the distribution differs only with a few per cent. The consistency is in particular strong with the low frequent causes to non-completions, this includes: equipment, space, safety, unexpected conditions, and rework. Finally, Table 2 reveals that approximately 25-30% of all scheduled activities end up as non-completions.

Table 2. A comparison of results between the three case studies.

	Case I		Case II		Case III	
	Registrations of occurrences	Registrations p. 100 planned activities	Registrations of occurrences	Registrations p. 100 planned activities	Registrations of occurrences	Registrations p. 100 planned activities
Unknown	286	12.77%	61	10.29%	265	10.22%
Connecting works	170	7.60%	12	2.02%	68	2.62%
Change in work plans	60	2.68%	11	1.86%	76	2.93%
Work force	56	2.50%	6	1.01%	72	2.78%
Weather conditions	29	1.30%	13	2.19%	50	1.93%
Materials	53	2.37%	18	3.04%	16	0.62%
Construction design	56	2.50%	8	1.34%	12	0.46%
Space	16	0.71%	2	0.34%	3	0.12%
Rework	12	0.53%	0	0.00%	1	0.04%
Equipment	5	0.22%	0	0.00%	3	0.12%
Unexpected conditions	1	0.04%	2	0.34%	3	0.12%
Safety	2	0.09%	1	0.17%	1	0.04%
Total	746	33.32%	134	22.60%	570	22.00%

The data collection consists of a weekly registration of non-completions in the three construction cases. By looking at the weekly percentage-wise allocation it is possible to test the results. To perform the T-test the registrations are grouped in clusters of three weeks. Hence, the three-week mean which appears in Table is a calculation of the percentage-wise frequency in relation to the total scheduled activities in a three week period. The three-week period is necessary to secure that a single registration will not induce a significant deviation in the results.

A two-tailed T-test was applied to test for means. The calculated confidence interval represents the interval, within which the observed mean with a likelihood of 95% would be situated. The actual interval is showed in the column named "Interval of population mean". Hence, non-completions related to construction design would with an accuracy of 95% lie within the range of [0.86; 1.93] percentage of the scheduled activities in a three week period. The small standard deviation and standard error calculated in Table 3 again witness a general consistency in the results.

Table 3. Comparison of statistic measures, standard deviation, standard error and the result from the applied T-test.

	Number of registrations	3 week Mean	Standard deviation	Standard Error of Mean	One sample T-test	
					95% Confidence Interval of population mean	Interval of population mean
Unknown	612	9.35	4.07	0.64	± 1.28	]8.06; 10.63]
Connecting works	250	3.81	3.13	0.49	± 0.99	]2.82; 4.79]
Change in work plans	147	2.41	1.64	0.26	± 0.52	]1.89; 2.93[
Work force	134	2.19	1.98	0.31	± 0.63	]1.56; 2.81]
Weather conditions	92	1.88	2.06	0.32	± 0.65	]1.23; 2.53[
Components and materials	87	1.63	1.93	0.30	± 0.61	]1.02; 2.24[
Construction design	76	1.39	1.70	0.27	± 0.54	]0.86; 1.93]
Space	21	0.39	0.78	0.12	± 0.25	]0.14; 0.63]
Rework	13	0.15	0.42	0.07	± 0.13	]0.02; 0.29[
Equipment and machinery	8	0.11	0.27	0.04	± 0.09	]0.02; 0.19]
Unexpected conditions	6	0.16	0.51	0.08	± 0.16	]0.00; 0.32]
Safety	4	0.08	0.27	0.04	± 0.09	] -0.01; 0.17[
Total	1450	23.55	--	--	--	--

4 DISCUSSION

Non-completions are a tangible problem in on-site construction. Thus there is a need for an increased robustness of the schedule. Implementation of LPS has had a positive effect on reliability, raising the PPC level to approximately 70% (Ballard 2000; Ballard 1999). In the three construction cases investigated the average PPC ended at 74.03%. From this follows that 25.97% of the scheduled activities are not completed on schedule and ends up as non-completions. Therefore, causes to non-completions has been registered in order to understand the problem which on-site production is facing and thereby reach even higher PPC levels. However, this is only regarded as the first step in the learning process. More in-deep research needs to be carried out to find the underlying root causes.

Of cause the high frequency of activities where the cause is not determined affects the results. Several explanations or distributions of the “unknown” category can exist: A) The “unknown” category can be caused by not identified categories or sources to non-completions; B) The “unknown” category could be non-completions related to a single or few categories were the registrations have not been correctly completed; C) The unknown category is common mistakes in the registration process, and should be equally distributed between all the identified categories; D) Finally the “unknown” category could be caused by a combination of A), B) and C).

The registration process has been directly observed which revealed that even though it was not registered, poor estimates of durations caused non-completions. Moreover, it was

observed that unknown registrations seem to be occurring when the time restrictions are causing the registration process to be speeded up. Besides the missing category it is not suspected that the distribution of causes within the “remaining” unknown registrations is different from the ones observed. Therefore, the distribution among the causes would be very close to the one presented. Though the effect would be that the frequency per 100 scheduled activities goes up which changes the calculated “Intervals for population mean”, see Table 3. For instance the frequency of non-completions caused by “connecting works” will be between 250 and 433 incidents depending on the number of unknown registrations caused by poor estimates of duration.

Furthermore, the direct observations revealed that every non-completion is registered in only one category, even so multiple causes can affect the completion process simultaneously. Again the missing registrations can be related to explanation A) B) or C) cf. the distribution of the “unknown” category. Since no pattern was identified, the missing registrations are expected to be equally distributed between the categories. Still, a more complete registration of causes will increase the frequency of incidents in the identified categories.

The results revealed six high frequent causes to non-completions respectively: connecting work, change in work plans, workforce, weather conditions, material, and construction design. Furthermore, the results revealed five low frequent causes to non-completions respectively: space, rework, equipment, unexpected conditions, and safety. Finally, when looking at results from the three cases separately, there was consistency between the low at high frequent causes to non-completions.

It is important to state that the consequence of a non-completion is connected to both frequency and impact. Impact includes the direct cost which is the direct measurable consequence and indirect cost which is uncountable and related to cost at either project, at individual, or at organizational level (Love 2002). The indirect consequence, which is much larger than the direct consequence, is estimated through a determined distribution of cost (Love 2002; Love and Li 2000; Burati *et al.* 1992). Therefore, it is very difficult to measure the total impact and consequence of a non-completion.

Impact is individual for each non-completion and will vary. Since impact has not been registered it is impossible to state if patterns exist in impact. To do so further research needs to be carried out. If patterns are discovered it could help managers in deciding where to intervene. Even though the impact is not known the results can still be used as guidance on where to intervene. The greatest effect, in relation to decreasing the number of non-completions, would be gained by focusing on preventing the high frequent causes. Therefore, since the impact is unknown, it would be rational to focus on preventing the high frequent causes.

When looking at the result two categories are quite surprising. It is surprising that the most frequent cause to non-completions is connecting works. The results indicate that the sounding process implemented to secure reliability in the schedule is not applied correctly. According

to the sounding process only activities where all preconditions are removed are allowed to be transferred to the Weekly Work Plans. This corresponds with the findings by Lindhard and Wandahl (2012) who find that activities with remaining constraints are allowed to enter the Weekly Work Plan. Furthermore, it could be a good idea to look at the buffer size. The high frequency of non-completions indicates that delays are too easily transmitted from one activity to another.

It is surprising how often the Weekly Work Plans change. The changes might have a different nature but the root cause would most likely be a complex and changing environment which forces the schedule to be rethought to optimize the output. Even so a changing Weekly Work Plan is not desirable. A schedule should be robust, reliable and trustworthy, and most importantly binding for all partners. If the schedule is continually changed it loses its credibility. Orders are no longer clear and simple, changes cause confusion which can lead to misunderstandings. A changing schedule can affect how contractors and craftsmen understand the schedule. Instead of commitments to a fixed deadline, it could now be understood more as a guidance.

Furthermore, a changing schedule can create a “separation of execution from planning” (Koskela and Howell 2001). This phenomenon occurs when the contractors neglect the project’s plans and schedules and instead work towards own priorities. It has previously been recorded as caused by unreliable scheduling and is followed by increased conflicts and non-completions which lead to low productivity (Koskela and Howell 2001). Thus, if a “separation of execution from planning” happened at the followed construction sites non-completions can simply be caused by commitments not being kept because the subcontractors work with own priorities.

Finally, it is important to state that the distribution of non-completion in relation to the 11 categories presented may vary noticeable depending on the type of construction project for instance offshore, road, refurbishment, housing etc.

5 CONCLUSION AND FURTHER RESEARCH

Three case studies were conducted in order to determine the different causes to non-completions of activities in construction. The studies revealed besides the “unknown” in total 11 different causes to non-completion. Six of them were high frequent causes respectively: connecting work, change in work plans, workforce, external conditions, material, and construction design. Furthermore, five were low frequent causes revealed respectively: space, rework, equipment, unexpected conditions, and safety.

A statistical analysis was performed where the 95% Confidence Interval of population mean was calculated with a two tailed T-test. During the analysis, it was found surprising that connecting works was the most frequent cause to non-completion. According to the sounding process this should not be possible, since all constraints should have been removed. The soundness of some constraints might vary but the completion of previous tasks cannot.

Therefore, the study revealed a misuse of the sounding process where unsound activities were moved to the Weekly Work Plans.

Another interesting finding was that the schedule was often rethought. Since the schedule ideally should be reliable and binding this is not desirable. Orders are no longer clear and simple, changes cause confusion which can lead to misunderstandings. Furthermore, it could have a negative effect on credibility where the schedule no longer is understood as a fixed deadline but just as a guidance.

This research was limited to look at the frequency of non-completions, further research could look at impact. Here, patterns could help managers to decide where to intervene.

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Learning From Constraints: Towards Increased Schedule Reliability in Onsite Production

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Abstract:

For years the construction industry has looked for ways to improve scheduling of onsite construction. Previous research has indicated that the development of Lean Construction and the implementation of Last Planner System successively has increased schedule reliability by increasing PPC from 35-60% to above 70%. Resurrecting constraints in activities in the Weekly Work Plans has been examined in relation to the seven preconditions. The purpose is to understand the varying nature of the preconditions in construction, to avoid repetitions, and to further increase schedule reliability. This research consists of two main studies. A questionnaire survey, which captures the experience from practitioners in the industry, and a case study, consisting of three cases where actual emerging constraints have been systematically recorded. Statistical comparison between the results from both the questionnaire and the case studies revealed consistencies between the two samples. From the studies it was revealed that non-completions most often was caused by constraints related to problems with construction design or connecting works.

Keywords:

Scheduling, Lean Construction, Preconditions, Constraints, Reliability

Introduction

The main reason for non-completions in on-site construction is emerging constraints. Non-completions create interruptions in the production work flow and result in decreased schedule reliability. In order to overcome non-completions in on-site construction the varying nature of construction constraints needs to be understood. Constraints in construction are caused by, among other things, the complexity of production in construction inherited from the production characteristics (Bertelsen and Koskela 2004; Bertelsen and Koskela 2004; Bertelsen 2003; Ballard and Howell 1995). The production process is managed by a temporary organization comprised of competing contractors with highly related and overlapping activities which have to be conducted within strict space limits. The production characteristics result in uncertainty (Seppänen 2009; Salem *et al.* 2006), and uncertainty creates variation in the production.

Last Planner System theory, from now on referred to as LPS, was introduced to minimize variation by increasing the quality and reliability of the production schedule. According to LPS, increased variation does lead to decreased productivity (Tommelein *et al.* 1999). The productivity decrease is induced by increased waste which emerges due to the extended use of working hours in the completion process (Rooke *et al.* 2007; Koskela 2004). Therefore, variations are critical and shall be avoided in an attempt to increase productivity in construction projects (Brodetskaia *et al.* 2011; Jang and Kim 2008; Thomas *et al.* 2003; Hopp and Spearman 2000; Ballard 1999b; Howell 1981).

Decreasing variation is achieved by applying LPS's four schedules, and according to lean construction theory the outcome should be an increased on-site effectiveness and productivity (Cho and Ballard 2011; Salem *et al.* 2005). The four schedules in LPS are: 1) The Master schedule; 2) The Phase schedule; 3) The Look-ahead plan; and 4) The Weekly work plans.

1) The Master schedule contains milestones and establishes an overview. 2) The Phase schedule secures the right sequence of work. The sequence is determined to optimize the process and to keep productivity high. 3) At the Look-ahead plan level activities are being made ready for conduction where after they are moved to a buffer. The buffer increases flexibility and thereby according to LPS theory improves the ability to respond to unforeseen events without affecting productivity in the workflows (Ballard and Howell 1995; Koskela 1992). 4) In the Weekly Work plans sound activities are selected and moved from the buffer and placed in the schedule (Authors 2012). Moreover, LPS contains a feedback and a learning system, which is called the PPC measurement. Through the learning process, root causes for non-completed activities are investigated and eliminated (Authors 2012).

The Look-ahead plan is a key element in LPS. It is designed to increase the reliability of the schedule (Dawood and Sriprasert 2006). Reliability is achieved by reducing uncertainty (Ballard 1999b). Furthermore, by reducing uncertainty, variation and waste decreases (Koskela 2004). Increasing reliability in the upstream activities will also improve work flow in downstream operations (Ballard 1999b).

To secure schedule reliability, constraints from the activities in the Look-ahead plan are removed. Removal of constraints is called the making ready process in LPS, and involves securing sound activities. Only sound activities are put into the Weekly Work Plan, comprising the actual production plan (Hamzeh *et al.* 2008; Steyn 2001; Ballard 2000). By only selecting sound activities, the success rate of completed tasks is increased and the workflow is stabilized (Ballard and Howell 1995; Ballard and Howell 1994), leading to increased robustness and reliability of the schedule (Liu and Ballard 2008). According to Ballard and Howell (1994), a stabilized workflow leads to a significant reduction in project duration and cost.

According to Lean Construction theory, the soundness of every individual activity depends on seven preconditions. An activity can only be conducted if these seven preconditions are fulfilled (Koskela 1999). Therefore, to increase schedule reliability, it is extremely important that no activity in the Weekly Work Plans lacks any of the following seven preconditions:

1. Construction design; correct plans, drafts and specifications must be available

2. Components and materials must be available
3. Workers must be available
4. Equipment and machinery must be available
5. Sufficient space to execute the task must be available
6. Connecting works, previous activities must be completed
7. External conditions must be in order.

Even though a high percentage of the planned activities have been completed after implementing LPS, there is still a need for a more reliable and robust plan (Ballard 2000). Right now the percentage of planned activities completed (PPC) level is stuck at the 70 -80 % level (Alsehaimi, Tzortzopoulos et al. 2009; Ballard 2000;). In the search for excellence, it is important to understand the causes of non-completions in construction. Besides poor scheduling, non-completions are caused by resurrecting constraints which results in non-sound activities being present in the Weekly Work Plan.

One central element in the lean philosophy is kaizen, or continuous improvement in the search for perfection. One approach to achieving perfection is to learn from failure. Therefore, in order to increase schedule reliability and reach the 90 % level or higher, the distribution of failure in relation to the preconditions needs to be explored (Authors 2011; Rooke *et al.* 2007; Ballard 2000; Ballard 1999a). Exploration of failure rates is done to enhance the understanding of the frequency of and likelihood for resurrection of the individual precondition. The big-picture can help create understanding, identify patterns, and an opportunity for learning. Thus, based on failure rates in the different preconditions, it can be determined where and how to intervene to prevent them from recurring. Root causes of failures are analyzed through the following research question:

How frequent do recurred constraints lead to non-completions in on-site construction, and how are the failures distributed between the seven preconditions?

Determining and understanding causes of failure is critical not only in the construction industry. Therefore, the research approach is relevant to project management in general. The research question is examined by: A) conducting a questionnaire survey to capture the experience of practitioners, and B) following three construction cases to identify actual distribution rates. Based on the findings confidence intervals are calculated. The confidence intervals are a statistical measurement expressing the interval wherein the frequency of a given constraint with 95% likelihood will be situated. The two studies are combined and a statistical hypothesis testing is carried out to look for consistencies between observed and perceived frequencies. Finally, the result of the statistical calculations is discussed.

Methods

The research design consists of two studies: A questionnaire survey, and three case studies. Both surveys look at resurrected constraints in relation to the seven preconditions. By applying two different data surveys a triangulation effect is achieved which adds validity to the results. To look for similarities and diversities between the surveys a statistical analysis of the data is applied.

The questionnaire survey

To collect practitioners' own experience with constraints emerging in the Weekly Work Plans an online questionnaire survey was conducted. The survey was conducted during a period of 40 days. The questionnaire was devised with outset in the designing theory presented in (Forza 2002). According to Forza (2002) four topics need to be considered: wording, scaling, respondent identification, and rules of questionnaire design. The wording is referring to the way questions are asked. In this process it is important to ensure a language which is consistent with the respondent's level of understanding, and to avoid leading or emotionally loaded questions. This has been ensured through a beta-test of the survey, where the questions and apprehension of the questions afterwards have been discussed, see Table 1. The question asked was: "Which precondition is most often the root-cause to non-completions: Number the preconditions from 1 to 7 depending on their likelihood for causing non-completions, 1 equals a very unusual cause while 7 is representing a very likely cause." A closed question was selected because it makes comparison between answerers possible. The selected scale was a Likert Scale with an uneven number of choices where the respondents could rate the likelihood with values from one to seven.

Respondent identification is regarding the identification of appropriate respondents in relation to the information required. Relevant respondents were ensured by securing that they were familiar with LPS either by A) practical experience of application of LPS or by B) theoretical knowledge achieved through their education. The respondents included: project managers, construction managers, site managers, and foremen with varying education and experience. In total 192 respondents were included in the survey. It has been considered acceptable that the same firm contributes to the survey with multiple questionnaires from different respondents. Forza's (2002) final topic concerns how the questionnaire is presented. To avoid any misunderstandings the questionnaire is presented by including an appropriate introduction and instructions.

The validity of the questionnaire survey is secured by creating trustworthiness of the study. According to Guba (1981) trustworthiness depends on four parameters which he at a quantitative study names: internal validity, external validity, reliability, and objectivity. In Table 1 the applied techniques to ensure trustworthiness is summarized.

Table 1: Applied techniques to ensuring trustworthiness of the questionnaire survey.

Questionnaire	
Internal validity	-Ensured that the same person did only participate once -Applying an electronic survey to expand the sample
External validity	-Demographic considerations, the selected participants did cover all different organizational levels and thereby contribute with different experience to production control to ensure an unbiased survey.
Reliability	-Triangulation of methods, by comparing the findings with findings from the case study -Peer-examination of methods, method is reviewed and discussed with peers. -Dense description of the research methods, allowing other researchers to follow the decision trail and to audit the results, see Guba (1981)
Objectivity	-Following a questioning technique to avoid affecting the responses.

The questionnaire process takes its outset in the strategy presented in (Akintoye and MacLeod 1997). First, an initial invitation was sent out to the participant. Secondly, if not replied, a

reminder was sent out two weeks later. In total 36 persons completed the survey resulting in a response rate of 19%. No completed questionnaires have been rejected by the authors due to incorrect answers.

Case studies

In addition to the questionnaire a case study was conducted. The case study research was carried out by following the three sub-steps: 1) Getting started, 2) Selecting cases, 3) which are presented in Eisenhardt's (1989) guidelines for case study research. In the first step the research focus is defined. The construction cases were followed with a focus on observing and determining constraint in the making ready process. It is important to keep a clear research focus else there is a risk to be overwhelmed by the massive data volumes (Eisenhardt 1989). Mintzberg (1979) states it like this *"No matter how small our sample or what our interest, we have always tried to go into organizations with a well-defined focus - to collect specific kinds of data systematically."*

In the second step cases are selected. Three cases were considered sufficient to achieve *"theoretical saturation"* (Romano 1989). When selecting the three cases two basic requirements were determined. A) LPS had to be fully implemented, including the PPC calculation. B) The constraints related to non-completions have to be reported and described. In the selection process, mail correspondences and phone conversations with company consultants and site managers secured the fulfillment of requirements. The second requirement was chosen to enable data collection from archives, and is thus related to Eisenhardt's (1989) third step. Thus, the archived summaries from scheduling meetings for the entire construction period were explored. The created triangulation of data sources, the archived data was in one construction case supplemented with on-site observation and meeting participation. To secure consistency in the results and to make comparison possible, the site manager was the same on all three construction projects. The cases are shortly presented in Table 3, which is followed by a short case description.

The research is conducted as a combination of qualitative and quantitative research. From three cases in total 4755 activities have been followed resulting in 1157 incidents where one or more constraints were not removed leading to a non-completion. In 454 incidents the root cause to the constraint has not been registered. Therefore, these incidents have been removed from the data set, limiting the incidents to a total of 703. The qualitative data-set secures a statistical validity of the collected data, and makes the statistical comparison possible while the supplementing on-site observations and meeting participation comprise the qualitative part of the research which places the non-completions into their context. It is important to know the context since the context can influence the results (Hartley 2004).

It is important to ensure research validity. Guba (1981) identifies four parameters to secure trustworthiness of a research study. At a qualitative research he names the categories: Credibility, transformability, dependability, and confirmability, while he at a quantitative names the categories: Internal validity, external validity, reliability, and objectivity. The applied techniques to ensure trustworthiness of the case studies are summarized in Table 2.

Table 2: Applied techniques to ensuring trustworthiness of the case studies.

Case studies: the qualitative part	
Credibility	- Triangulation of data sources, by following 4 different construction cases - Prolonged engagement, making observations over a period of time to identify recurrent patterns c.f. (Lincoln and Guba 1985) -Peer examination, see Lincoln and Guba (1985). Discussing the research processes and findings with peers.
Transformability	-Demographic considerations, where construction sites involving different companies were followed to capture differences in application, see Krefting (1991).
Dependability	-Dense description of the research methods, allowing other researchers to follow the decision trail and to audit the results, see Guba (1981). -Peer-examination of methods, see Lincoln and Guba (1985).
Confirmability	-Reflexivity, considering researches influence on the observed and seek towards neutrality, see Guba (1981).
Case studies: the quantitative part	
Internal validity	-Dependent variables are isolated -Prolonged measurement to ensure a large data sample to minimize the risk of randomization
External validity	-Following more cases to expand the data sample and to make generalizations possible, c.f. Payton (1979). Including different companies and different categories of construction projects (housing and refurbishment).
Reliability	-Hypothesis testing of results to document reliability -Peer-examination of methods -Dense description of the research methods, allowing other researchers to follow the decision trail and to audit the results, see Guba (1981)
Objectivity	-Data collected mainly forms archives. By observing the registration it was insured that the site-manger did rigoursly follow the defined methods for registration.

Table 3: Data collection at the three case-studies

	Case 1	Case 2	Case 3
Contract form	Turnkey contractor	Turnkey contractor	General contractor
Project followed	Entire construction period	Entire construction period	Entire construction period
From archives	Reports from LPS meetings	Reports from LPS meetings	Reports from LPS meetings
Construction period	50 weeks	23 weeks	60 weeks
Activites registered	1570 activities	593 activities	2592 activities
Constraints registered in	453 activities	134 activities	570 activities
Average PPC	71.1 %	77.4 %	78.0 %

Case one: Housing

Case one was a renovation project of 16 three-storey residential apartment blocks containing a total of 309 flats. The blocks were dispersed between 5 blocks containing 15 flats, 11 blocks containing 21 flats, and additionally 3 handicap or senior houses. The project included rehousing of the residents. Rehousing was limited to a period of 7 week's length. This was followed by a period of one week's length where the residents could compose a discrepancy list, and finally a one week's period for repairing the deficiencies. The project contract value was \$4.45 million, with a duration fixed on 26 months.

Case two: Educational institution

Case two was construction of an educational institution. In total 6 different university educations were later on located in the buildings. The project consisted of two buildings, in total 11000 m². The main building was a three-storey building plus basement, in total 8000 m² and has an autonomous contract value on \$21.75 million. The secondary building was a two-storey building with no basement, in total 3000 m². In total the secondary building had an autonomous contract value on \$7.36 million. The project was prestigious and modern and had to meet the highest standards within sound, fire, ventilation, intelligent control, etc. Simultaneously the construction period was restricted to 16 months. Therefore, as a turnkey contractor, the primary focus was on keeping the production flows running.

Case three: Nursing home

Case three was construction of a nursing home. The project consisted of 6 one-storey apartment blocks in a nursing home. In total 68 flats. The blocks were dispersed between 2 blocks with 10 flats and 4 blocks with 12 flats. Additionally the project included the construction of 4 common houses. The contractor worked as a prime contractor and had the primary responsibility with concrete, soil, sewer, concrete elements, steel, and weather covering. The project contract value was \$3.89 million, with a contract period of 17 months.

Statistics and comparison

All observations from both the questionnaire and the three case studies are considered statistical independent. The depended variables were measured on a fixed interval scale set to vary between 1 and 7 depending on frequency of the constraint. Furthermore, all incidents of differences were assumed to be normal distributed in the population.

In the questionnaire the participants were asked to number the likelihood of constraints in relation to the seven preconditions. The minimum value (1) represents a most unlikely occurrence while the maximum value (7) represents the most likely occurrence.

The case studies consisted of a weekly registration of constraints in three construction cases. To be able to compare and test results, the percentage-wise allocation of the constraints were calculated in relation to the total number of activities in the corresponding Weekly Work Plans. To strengthen the frame of reference the weekly registrations were compiled in clusters of three. Afterwards the distribution of occurrences of constraints was transformed to the 7 step scale using the transformation diagram shown in Table 2. The transformation diagram was developed to relate and compare results from the two research studies.

Table 4: Transformation diagram from occurrence in percentage of total activities in the 3 week cluster into the fixed 7 step scale. The transformation diagram is developed to enable a comparison between the results from the questionnaire and the case studies.

$6,25\% \leq x \leq 100\%$	\Rightarrow value 7
$4,50\% \leq x < 6,25\%$	\Rightarrow value 6
$2,75\% \leq x < 4,50\%$	\Rightarrow value 5

$$\begin{aligned}
 1,75\% \leq x < 2,75\% &\Rightarrow \text{value 4} \\
 0,75\% \leq x < 1,75\% &\Rightarrow \text{value 3} \\
 0\% < x < 0,75\% &\Rightarrow \text{value 2} \\
 x = 0\% &\Rightarrow \text{value 1}
 \end{aligned}$$

First a hypothesis test of means from the individual results was carried out. Since the sample deviation (σ) is unknown a one sample T-test is applied to test the means. The H_0 and H_A hypothesis is respectively:

$$H_0 : \mu = \mu_0$$

$$H_A : \mu \neq \mu_0$$

The test statistics applied is: $t = \frac{\bar{X} - \mu_0}{s/\sqrt{n}}$; with the level of significance set to: $\alpha = 0,05$. The

calculated confidence interval represents the interval the population mean with a likelihood of 95 % would be situated within. By stating that $\mu_0 = \bar{X}$ the lower and upper boundaries for the population mean would be calculated. These boundaries should respectively be subtracted or added to the sample mean.

Afterwards the results from the questionnaire were compared to the case-observations. Since the sample deviation (σ_1, σ_2) is unknown but equal ($\sigma_1 = \sigma_2$) a squared T-test was applied to test the paired means. The H_0 and H_A hypothesis is respectively:

$$H_0 : \mu_1 = \mu_2$$

$$H_A : \mu_1 \neq \mu_2$$

The test statistics applied is: $t = \frac{(\bar{X}_1 - \bar{X}_2) - \delta}{\sqrt{s_p^2/n_1 + s_p^2/n_2}}$; with the level of significance set to:

$$\alpha = 0,05.$$

When stating that $\mu_1 = \bar{X}_1 = \mu_2 = \bar{X}_2$ the calculated confidence interval represents the interval of the observed difference in mean with a likelihood of 95 % would be situated within.

Furthermore, since the questionnaire consisted of multiple independent values arranged in random order, calculation of correlation between the results does not make any sense. Therefore, no effort was done calculating the linear association between the results from questionnaire survey and the case-studies.

Results

A questionnaire was designed to capture project managers, construction managers, site-managers and foremen's experience with failures in the making ready process. The results, which are presented in Table 5 show the expected average frequency of constraints in relation to the seven preconditions. It shows a high frequency in constraints related to construction design

and connecting works. Table 5 does also contain the statistic measures standard deviation and standard error. Furthermore, a two-tailed t-test was performed ($\mu_0 = \bar{X}$) and the related interval for the population mean is stated. The interval for the population mean is important because it expresses the interval where the frequency of a constraint at 95 % likelihood will be situated. Thus, the interval can be used to predict the frequency of future incidents.

Table 5: Causes to non-completions. Minimum average is 1 representing the most unusual reason for non-completions while maximum average is 7 representing the most likely reasons for non-completions.

	Respondents	Average	Standard deviation	Standard Error of Mean	One sample t-test	Interval of population mean
					95% Confidence Interval of population mean	
Construction design	36	5,58	1,90	0,32	$\pm 0,64$	[4,94; 6,23[
Connecting works	36	4,83	1,90	0,32	$\pm 0,64$	[4,19; 5,48[
Space	36	4,08	1,66	0,28	$\pm 0,56$	]3,52; 4,65[
Components and materials	36	4,03	1,72	0,29	$\pm 0,58$	[3,45; 4,61[
Equipments and machinery	36	3,56	1,59	0,27	$\pm 0,54$	[3,02; 4,09]
External conditions	36	3,47	2,09	0,35	$\pm 0,71$	]2,76; 4,18[
Work force	36	3,22	2,02	0,34	$\pm 0,68$	]2,54; 3,90]
Total	36					

In a second study three construction cases were followed. In the three cases occurred non-completions were registered as a measurement for emerging constraints. This included both failures in the making ready process but also failures which developed after the making ready process. In 703 incidents constraints were registered and the root causes determined in relation to the seven preconditions. The findings are presented in Table 6 in the column named ‘number of registrations’. Again a high frequency in constraints related to construction design and connecting work was registered.

To enable comparison with the questionnaire survey the collected data was split up in weekly registration and transformed into a similar scale. Furthermore, the statistic measures mean, standard deviation, standard error, and the confidence interval for the population mean was calculated. Finally, a two-tailed t-test was performed ($\mu_0 = \bar{X}$) and the related interval for the population mean is stated. Again the interval for the population mean is of particular importance because it can be used to predict the frequency of future incidents. The results are presented in Table 6.

Table 6: Causes to non-completions divided between the seven preconditions. Minimum average is 1 representing the most unusual reason for non-completions while maximum average is 7 representing the most likely reasons for non-completions. It is important to stress that construction design additionally contains issues caused by site management and does for instance include schedule changes.

	Number of registrations	3 week Mean	Standard deviation	Standard Error of Mean	One sample t-test	Interval of population mean
					95% Confidence Interval of population mean	
Construction design	204	5,14	1,31	0,22	± 0,45	]4,69; 5,59]
Connecting works	194	4,40	2,03	0,34	± 0,70	]3,70; 5,10]
External conditions	105	3,51	1,94	0,33	± 0,67	]2,85; 4,18]
Work force	104	3,43	1,63	0,28	± 0,56	]2,87; 3,99[
Components and materials	72	2,80	1,83	0,31	± 0,63	]2,17; 3,43[
Space	17	1,57	1,01	0,17	± 0,35	]1,23; 1,92[
Equipment and machinery	7	1,23	0,54	0,09	± 0,19	]1,04; 1,41]
Total	703					

Distinct similarities between results of the two studies and thus observed and perceived frequencies can be evaluated by comparing differences in mean. A better glimpse of the relationships and consistency between the results is achieved by making a hypothesis testing, where correlations between the two sets of data set are controlled. Here, a two-tailed squared t-test was performed. If the value of t lies within the corresponding confidence interval the H_0 hypothesis is accepted, if not H_0 is rejected and instead H_A accepted. The results are presented in Table 7. The test revealed a high consistency between constraints related to external conditions, connecting activities, work force, and construction design. Furthermore, a low consistency was revealed between equipment and machinery, materials and components, and space.

Table 7: Squared T-test where the questionnaire (q) is paired to the case (c) results

	Paired Differences					t
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		
				Lower	Upper	
Construction design (q-c)	0,43	2,33	0,40	-0,37	1,23	1,09
Work force (q-c)	-0,17	2,50	0,42	-1,03	0,69	-0,41
Materials and components (q-c)	1,20	2,70	0,46	0,27	2,13	2,63
Equipment and machinery (q-c)	2,34	1,83	0,31	1,71	2,97	7,57
Space (q-c)	2,51	1,76	0,30	1,91	3,12	8,48
Connecting activities (q-c)	0,37	2,97	0,50	-0,65	1,39	0,74
External conditions (q-c)	0,03	2,70	0,46	-0,90	0,95	0,06

Discussion

Non-completions, which decrease schedule reliability, are a fact in construction. The Implementation of LPS has only raised the PPC level to between 70-80% (Alsehaimi, Tzortzopoulos et al. 2009; Ballard 2000; Ballard 1999a). The PPC level is supported by the three construction cases where the average PPC was calculated to be 75.7%. Therefore, in order to understand the problems in construction scheduling, and by this means reach even higher PPC levels, constraints in construction have been registered. To secure validity, a triangulation effect was achieved by conducting both case studies and a questionnaire survey.

Statistical comparison of the results from both the questionnaire and the case studies revealed consistencies between the two samples. In both studies construction design and connecting work were respectively the most frequent causes for not ready activities. Furthermore, by testing means by performing a two-tailed squared t-test consistency was found in the frequency of constraints related to: external conditions, connecting activities, work force, and construction design.

Construction design was registered as the most frequent cause to non-completions in on-site construction. The importance of construction design is supported by Al-Momani (2000) and Assaf and Al-Hejji (2006), in both studies design is identified as the main cause to delay in construction. The many occurrences of constraints related to construction design could indicate a need for an improved communication and collaboration between the design and execution units, and between the different trades on site. Often the site-manager has no possibilities for forecasting or affecting these occurrences. By improving communication and collaboration these processes could be integrated as one interconnected process; instead of as today were it consists of many autonomous processes. Moreover, new technologies such as BIM can be implemented to support communication and collaboration and help in revealing design conflicts. BIM is enabling an automatic detection of design clashes. By detecting the clashes on beforehand, many design conflicts can be prevented from reaching the construction site (Brandon and Kocatürk 2009) which according to Azhar (2011) could induce savings in the contract value of up to 10% and moreover reduce project duration with up to 7%. It is important to state, that it is out of the limits of this research to determine the actual cause to the high number of constraints related to construction design. Thus, additional research has to be conducted.

The high frequency in constraints related to connecting works indicates a tremendous proportion of rework, a high number of at risk activities, or an incorrectly applied sounding process. At risk activities are activities which still contain constraints when scheduled, but the constraint is expected to be removed before conduction (Liu and Ballard 2008). One constraint could be a dependency to the completion of the work-in-progress. An incorrectly applied making ready process results in non-ready activities being moved to the Work Plans without ensuring soundness. The tendency to skip the making ready process has previously been documented by Koskela and Howell (2001). Even though delays are easily transmitted in construction, the magnitude of the effect indicates, what previous research has shown, namely that an adequate buffer size only very rarely is applied in construction (Authors 2012). Thus, delay can be

absorbed without affecting the workflow by incorporating a small buffer between two interrelated activities.

It is important to notice that non-completions in relation to both construction design and connecting works are derived from prior project management. Construction design and connecting works constitute 398 out of the 703 non-completions registered, which corresponds to 57 % of the total registrations. In a negative aspect the number reveals a poorly performing management, while the number in a positive aspect reveals an opportunity to improve within managerial processes. It is important to notice that improvement can be achieved inside managerial control, thus no external constraints affect the incidents. Moreover, this underlines the importance of communication, collaboration and a correctly applied LPS.

The level of significance did also reveal differences in the results. No consistency was found in frequencies of constraints related to equipment, materials, and space. In these incidents the discrepancy in results was conspicuous distinct. Causes and frequency of constraints would vary between projects and project types. In this study only refurbishment and housing projects are included. Despite differences in constraints between different types of construction project, offshore, road, refurbishment, housing etc. are expected, the results are still conflicting. Thus, an explanation to the differences in results has to be found elsewhere.

One could claim that the explanation could be related to the data transformation, where the data from the case studies were made comparable to the results from the questionnaire. Even so, this will only have a slight effect on the end results. Furthermore, differences in results are clear when data is compared before the transformations process. Constraints related to equipment, materials, and space have only been registered respectively 7, 17 and 72 times out of 703 incidents.

Since the results from the questionnaire are based on on-site experience, the source to the differences in results compared with the case-study could be explained by wrong perceptions. From this it can be deduced that there in the industry is an incorrect perception between experienced frequency and actual frequency of constraints related to equipment, materials, and space.

The reason to the wrong perceptions would probably be related to how these occurrences are experienced. Future research has to explain why. Explanations could be related to cost or consequences of the incidents i.e. hard and physical parameters. Or the explanation can be found in soft and psychological parameters. Maybe breakdowns, missing material or insufficient space are in particular resulting in a higher degree of annoyance, frustrations or stress. Most likely it is a combination.

One of the steps towards reaching a higher PPC level in construction is to understand the root causes. Therefore, it is important that the industry in general realizes the actual frequency and distribution of constraints between the 7 preconditions. Moreover, it is important to understand the varying nature of the preconditions.

Kaizen or continuously improvements is a part of the lean philosophy. Improvements are achieved by learning from previous mistakes because repetitions hereby are avoided. By avoiding repetitions decreased variation is gained. Reduced variation is increasing schedule reliability and schedule robustness. In LPS continuous improvement is achieved by identifying root causes to learn from mistakes and to avoid repetitions. The wrong perceptions could be explained by a lacking effort to identify root causes and learn from mistakes. If root-causes have been systematically identified the respondents might have had more insight into causes and frequencies. Thus, the misconceptions underline the importance of the follow-up and learning process in LPS. Missing implementation of the learning system is supported by Authors (2012). The learning element could be implemented by applying the lean tool “the 5 whys”. Moreover, unsound activities could be reduced by implementing a weekly “health check” when selecting next week’s work activities. Through the “health check” the fulfillment of the preconditions is controlled to decrease the likelihood of undiscovered or resurrecting constraints. Early uncovering of non-sound activities reveals time to make changes and adjustments in the schedule which decreases the effect of variation. Furthermore, it secures that the workflow can proceed without interruptions which brings productivity up.

The consequence of a constraint is connected to both frequency and impact. Impact includes the direct cost which is the direct measurable consequence, and indirect cost which is immeasurable and related to cost at either project, individual, or organizational level (Love 2002). The indirect cost is much larger than the direct cost (Love 2002; Love and Li 2000; Burati *et al.* 1992). Therefore, it is very difficult to measure the total impact of a constraint.

In relation to schedule reliability the effect of a constraint is always that it obstructs the completion of an activity, and by interrupting the workflow, according to LPS theory, decreases productivity. If only schedule reliability was the target, high frequency of non-completions would be determining for where to intervene. Thus, in order to increase schedule reliability the focus should be put into eliminating resurrections of constraints related to construction design and connecting work. Another argument for focusing on non-completions related to construction design and connecting work is that both constraints are that intervention is simplified because both constraints are within managerial control. Even so, the impact is still individual for each incident. Therefore, the consequence of the incidents will vary. Since impact has not been registered, it is impossible to state if there are patterns in impact. To do so further research needs to be carried out. If patterns are discovered it could help managers decide where to intervene in order to learn from failures to increase productivity.

Conclusions

Non-completed activities have been examined in order to create an understanding of the likelihood of emerging constraints in relation to the seven preconditions of construction. The distribution of failures caused by emerging constraint in the Weekly Work Plans was examined through A) a questionnaire survey to collect industry experience and B) through 3 case studies to supplement the experience with actual incidents. Because of the triangulation effect multiple

data sources increases the validity of the survey. Finally, the result was compared in a statistical analysis.

The analysis revealed both similarities and diversities between the surveys. In both surveys constraints related to construction design and connecting work were respectively the most frequent causes to not ready activities. Non-completions caused by both construction design and connecting work are inside managerial control, thus both constraints are derived from prior project management. Reducing constraints within managerial control simplifies the intervention because the problems can be isolated from external constraints. Since impact has not been registered, it is impossible to state where to intervene to gain the biggest effect. Even so, two arguments to focus on construction design and connecting works are presented in the discussion, firstly the high frequency and secondly that these two constraints are within managerial control which simplifies the intervention process. In general all preconditions should be observed to avoid unexpected constraints. By intensely following the soundness of the individual activities the triggers can be identified bringing the number of unexpected constraints down.

When testing means by a squared T-test constraints related to external conditions, connecting activities, work force, and construction design revealed consistence. Moreover, no consistency was found in frequencies of constraints related to equipment, materials, and space. In these incidents the discrepancy in results was conspicuous distinct.

Differences in results were found to be caused by incorrect perception between the experienced and actual frequency of these preconditions in the industry. An explanation could be related to both physical and psychological parameters which affect how these occurrences are experienced. To explain the relationships more accurately further research will need to be carried out. Future research could also look into how perceptions which differs from reality emerge.

Furthermore, the study unexpectedly revealed that LPS often is misused. An adequate buffer size is not applied, root causes to mistakes are not found, and no attention is put into learning from mistakes. By misusing LPS the positive effects on variation, robustness etc. will decrease. Furthermore, since learning is not applied, potential improvements in scheduling reliability are lost.

Future research is necessary to explain and identify the actual root causes to why constraints are emerging. By identifying root cases and triggers patterns of impact might be revealed. Impact is important because it together with frequency determines the consequence of an issue. To identify impacts, further research is necessary.

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Improving Onsite Scheduling: Looking Into the Limits of the Last Planner System

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Abstract

Scheduling of onsite construction is complex. The Last Planner System (LPS) has been successfully implemented on construction projects to handle variation and to increase schedule reliability. By focusing on fulfillment of preconditions of each activity the amount of non-completions has decreased. In an attempt to further refine the LPS scheduling methodology, the scheduling system has been studied and discussed. The research is based on four case studies and complemented with a review of relevant LPS theory. The research revealed several areas in the existing scheduling system, which could be improved. The absence of flow, quality, critical path, and slack is critical when determining the optimal sequence in the Phase Schedule. Expanding current selection criteria (dependencies and duration) will increase reliability of the sequence, which evidently will improve the efficiency of the schedule and increased productivity onsite. Furthermore, it was discovered that craftsmen's comfort and motivation need to be taken into account. Also precautions to avoid congestions in the making-ready process should be implemented, along with a continuous control of soundness of every task. If these weaknesses are treated, the LPS system will lead to further increase of schedule reliability and possibly onsite productivity.

Keywords: lean construction, Last Planner System, sequencing, scheduling

Introduction

The execution process in the construction industry is dominated by complexity and uncertainty (Aritua *et al.* 2009; Dubois and Gadde 2002). Multiple contractors are subject to firm time, and must conduct interdependent and overlapping activities (Ahmad and An 2008; Bertelsen and Koskela 2004; Bertelsen 2003; Ballard and Howell 1995). Delay is easily transferred from one activity to another, which makes it difficult to keep a realistic schedule (Salem *et al.* 2006; Bertelsen 2004; Howell and Ballard 1994). Different approaches for optimizing the scheduling process exist. The following is based on a study of the Last Planner System (LPS). LPS is based on lean principles, and seeks to improve the quality and reliability of the schedule as a road to increased productivity (Liu and Ballard 2008). The LPS methodology implements four schedules: 1) The Master Schedule 2) The Phase Schedule 3) The Look-ahead Plan 4) The Weekly Work Plans (Lindhard and Wandahl 2012b; Ballard 2000).

The Master Schedule is the result of the initial planning. It is based on several uncertain parameters which, among others, are caused by the unpredictable nature of the construction process. The Master Schedule points

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out what should be executed and contains main activities and milestones (Howell and Ballard 1994). Furthermore, the Master Schedule serves as guidance for the lower level of planning (Ballard 2000). According to LPS, it is important not rigorously to adhere to the initial schedule but instead continuously update the Master Schedule as deviations in the basis of the schedule will occur (Tommelein 1998). If the underlying assumptions change the schedule as well needs to be changed.

The next step in LPS is the Phase Schedule which secures a thought through sequence and structure of work (Ballard 2000). Phase scheduling is an important part of LPS, and Ballard and Howell (2003) point out that: *“Phase Scheduling is the link between work structuring and production control. Without it, there is no assurance that the right work is being made ready and executed at the right time to achieve project objectives.”*

Based on the Master Schedule the project is divided into main-phases. Milestones in the Master Schedule form a natural border between these phases. Working backwards helps identifying handoffs between crews which restrict the sequence (Hamzeh *et al.* 2008; Ballard and Howell 2003). An essential part of the Phase Schedule is the involvement of all subcontractors in this process. The quality of the Phase Schedule is dependent of all subcontractors actively engaging in the scheduling process (Ballard and Howell 1994). Often unforeseen interdependencies between subcontractors surface during this process, forming important restrictions to the sequence (Howell 1999). The sequence is traditionally carried out by letting the involved subcontractors order their activities on PostIt notes. To incorporate interrelations it is important to include relations and connections to both previous and following activities. The PostIt's are afterwards put onto a whiteboard and collaboratively re-structured to achieve the best sequence (Ballard and Howell 2003; Ballard 2000).

The third schedule is the Look-ahead Plan which is the backbone of LPS (Lindhard and Wandahl 2012b). Look-ahead planning secures that activities can be completed by ensuring that scheduled activities are sound (Ballard 2000). In LPS terms this is called the making-ready process, and it is here constraints to each activity are identified and removed (Jang and Kim 2008).

According to the LPS theory the soundness of an assignment depends on seven preconditions (Koskela 1999). An activity can only be completed if all these seven preconditions are fulfilled (Koskela 1999). The seven preconditions are:

1. Construction design; correct plans, drafts and specifications are present
2. Components and materials are present
3. Workers are present
4. Equipment and machinery are present
5. Sufficient space so that the task can be executed
6. Connecting works, previous activities must be completed
7. External conditions must be in order

Recently research has proposed to divide “external conditions” into three new categories (Lindhard and Wandahl 2012a). In the current form the “external conditions” category covers several subcategories. Putting a name on the specific subcategories brings increased awareness and attention to the preconditions in the making-ready process and avoids the risk that the site-manager overlooks remaining constraints. The “external conditions” category was divided into the following:

- 7a. Climate conditions must be acceptable. The preconditions focus on external environmental effects such as rain, snow, wind, heat, cold etc.
- 7b. Safe working conditions must be present. The national “Health and Safety at Work Act” has to be obeyed to keep employees safe.

- 7c. The surrounding conditions must be known. The precondition focuses on securing that existing conditions, if necessary, are examined. Problems often arise during excavations or refurbishment assignments.

Activities become sound by analyzing all preconditions for each activity that is scheduled for conduction in a time frame of up to 6 weeks into the future. In LPS this time frame is called the “look-ahead window”. The fulfillment of the preconditions secures that manpower, machinery, material, etc. are pulled to the construction site Just-In-Time (Vishal *et al.* 2010; Chua *et al.* 1999; Tommelein 1998).

The Look-ahead window is a drop-out from the Master Schedule and forms a link between the Master Schedule and the Weekly Work Plans (Kemmer *et al.* 2007; Chua *et al.* 1999). The length of the look-ahead window depends on project characteristics, the reliability of the planning, and the needed duration for making activities sound and will normally vary between 3-12 weeks (Ballard 2000).

Each week the look-ahead window is sliding one week forward. When sliding the look-ahead window forward only activities expected to be made ready on schedule are sliding forward (Ballard 2000). An activity with all preconditions fulfilled is moved to a buffer containing a workable backlog of activities which are ready for execution. Selecting activities to the Weekly Work Plan only from this buffer secures that the Weekly Work Plan contains only sound activities (Hamzeh *et al.* 2008; Steyn 2001; Ballard 2000; Howell and Ballard 1994). Furthermore, the workable backlog serves as a buffer against unexpected conditions that could constrain the scheduled activities. The buffer is the connection between the Look-ahead Schedule and the Weekly Work Plans. The buffer adds flexibility to the robustness and increases the adaptability of the schedule which helps maintaining a constant workflow.

The final and fourth schedule in LPS is the Weekly Work Plan (Ballard 2000). Sound activities are selected from the buffer and the final and binding commitments of what will be completed the following week are made (Ballard and Howell 1998).

Additional to the Weekly Work Plans, LPS implemented a feedback and learning system called the PPC (Percent Plan Complete) measurement (Ballard 2000). In this feedback system, scheduled activities are compared with the completed activities which provide a picture of schedule reliability and schedule quality (Hamzeh *et al.* 2012). Thus, non-completed activities are identified. In the search for continuous improvement root causes to non-completions are found and eliminated to avoid repetitions and improve the scheduling process (Ballard *et al.* 2009; Ballard 1994; Howell and Ballard 1994). Learning from failures increases PPC and the quality of the schedules which leads to productivity improvements.

Research shows that implementation of LPS has increased the number of planned activities completed (PPC) from 30-60 % to around 70 % (Ballard 1999). But the PPC level is right now stuck at the 70% level (Ballard 2000). To help construction reaching an even higher PPC level the scheduling process, therefore, needs to be further analyzed and improved. The first step is to analyze LPS in order to understand the process and to identify limitations in the current methodology. Therefore, LPS is examined through the following research question:

Can LPS be further improved? And what are the benefits and shortcomings of the current LPS scheduling methodology?

The introduction section above contains a general and theoretical introduction to LPS which is a lean based scheduling tool. Thus, the research does not look into Lean Construction in general but is limited to focus only on LPS. Therefore, only research directly related to LPS has been found relevant. In the following the methodology and methods are explained. In the result section the identified pros and cons are revealed and afterwards discussed in the discussion section.

Research methodology and methods

The research was based on four construction cases which have been carefully selected. The selection criteria were A) LPS must be implemented. B) The contractor should minimum act as general contractor with associated subcontractors. The selection criteria were added to increase the validity and quality of the research.

To gain insight into LPS, actual application of the scheduling system was observed, archives were inspected, and interviews with site-managers were carried out. This case study took its outset in Eisenhardt's (1989) guidelines. An explorative approach, where application of LPS could be observed, was chosen. Moreover, the qualitative approach was chosen so that LPS could be analyzed contextually. Only in its context the actual application of LPS can be examined and understood. This is supported by both Eisenhardt (1989) and Yin (2003) who state that how and why questions only can be answered with qualitative research. To ensure a well-defined research focus, the objective and research focus of the case-studies were clarified on beforehand and relevant observations and data were determined. The importance of research focus is supported by Mintzberg (1979) who states "*No matter how small our sample or what our interest, we have always tried to go into organizations with a well-defined focus - to collect specific kinds of data systematically.*" The onsite observations were supplemented by archived data of former plans and schedules directly downloaded from the contractor's database and through interviews with site-engineers.

The interviews were conducted as semi-structured following the interviewing guidelines of Ritchie *et al.* (2005). Interviews were completed individually for every site manager as a face to face interview. Before the interviews were completed the site managers and the interviewer meet at several occasions to gain mutual trust which according to Oakley (1981) is essential for face to face interviews. Only the oral communication was of interest. Therefore, no effort was put into capturing kinesic, paralinguistic, or chronemic data. Prior to each interview a number of open ended questions were prepared to help structuring the interview and to ensure that all important topics were covered. Wengraf (2004) suggests that open ended questions are prepared having in mind that questions cannot be planned in detail, since the informants response cannot be predicted in advance. Therefore, questions must be improvised in a theorized and deliberated way (Wengraf 2004).

The interviews were conducted to support and supplement the onsite observations. Moreover, multiple research approaches do add triangulation which increases research validity. Because of the mixed research approach, the contribution of each approach is summarized in Table 1.

Table 1: Clarification of how the research approaches contributed to the results

	Master Schedule	Phase Schedule	Look-ahead Plan	Weekly Work Plan
Primary contribution to results	Interviews with site-managers	Interviews with site-managers	Onsite observations	Onsite observations
Sub-contributor to results		Onsite observations of conflicts		Archives, used to follow PPC-levels

An overview of the data collection from each of the four cases is shown in Table 2. Afterwards, each case is briefly described. Collected data in combination with LPS theory found the basis for the subsequent analysis resulting in a list of pros and cons in regards to current LPS methodology.

Table 2: Data collection at the four case-studies

	Case 1	Case 2	Case 3	Case 4
Contract form	Turnkey contractor	Turnkey contractor	Prime contractor	General contractor
Site observations	Once every fortnight in total 5 observations.	1-2 times every fortnight in total 8 observations.	1-3 times every fortnight in total 8 observations	1 time every week in total 6 observations
Meetings participated in	Subcontractor, foremen and safety meetings	Subcontractor and LPS meetings	Subcontractor, foremen, emergency and construction meetings	Scheduling of Weekly Work Plans
Observation length	10 weeks	10 weeks	10 weeks	6 weeks
Interviews of site-manager	5 unstructured and 1 semi-structured	8 unstructured and 1 semi-structured	8 unstructured and 1 semi-structured	6 unstructured and 1 semi-structured
From archives	Reports from meetings, various schedules and organisation charts	Reports from meetings and various schedules	Reports from meetings and various schedules	Schedules

Case one: Housing

Case one was a renovation project of 16 three-storey residential apartment blocks, containing a total of 309 flats. The blocks were dispersed between 5 blocks containing 15 flats, 11 blocks containing 21 flats, and additionally 3 handicap or senior houses. The project included rehousing of the residents. Rehousing was limited to a period of 7 weeks. This was followed by a period of one week where the residents could compose a fault and deficiency list, and finally a one week period for repairing the deficiencies. The project contract value was \$4.45 million, with a duration fixed to 26 months.

Case two: Educational institution

Case two was construction of an educational institution. The project consists of two buildings in total 11000 m², and should service 6 different university programs. The main building was a three-storey building plus basement, in total 8000 m² and has an autonomous contract value on \$21.75 million. The secondary building was a two-storey building with no basement, in total 3000 m². In total the secondary building had an autonomous contract value on \$7.36 million. The project was prestigious and modern and had to meet the highest standards within sound, fire, ventilation, intelligent control, etc. Simultaneously the construction period was restricted to a duration of 16 months. Therefore, as a turnkey contractor, the primary focus was on keeping the production flows running.

Case three: Nursing home

Case three was construction of a nursing home. The project consists of 6 one-storey apartment blocks in a nursing home. In total 68 flats. The blocks were dispersed between 2 blocks with 10 flats and 4 blocks with 12 flats. Additionally the project includes the construction of 4 common houses. The contractor worked as a prime contractor and had the primary responsibility for in-situ concrete, soil, sewer, concrete elements, steel, and weather covering. The project contract value was \$3.89 million, with a contract period of 17 months.

Case four: Hospital

Case four was the refurbishment of a top floor-section at a hospital. The renovation project was carried out while the hospital was fully functioning. This limited the access to the site and complicated the logistics because

materials could only arrive late night to early morning. The renovation project had a contract value at \$5.5 million, and a contract period of 7 months.

Results

In the following, the data from the four construction cases is presented. In outline, the structure of the results section is divided into the four schedules composing the LPS methodology.

Master Scheduling

The Master Schedule has in all four cases been forming the borderlines to the construction project. Thus, the purpose of the Master Schedule has been to create a holistic understanding of the entire upcoming construction process. The Master Schedule was based on milestones and key deadlines from the contracts. In the four cases this schedule was following either a Gantt or a Location-Based methodology. To maintain overview and transparency the detail level has been kept low, thus only the main activities were included. Moreover, only estimated durations have been of interest at the Master schedule level. Thus, there was no focus on buffers, flows, or constraints at this level.

Phase Scheduling

Phase scheduling has been implemented as a systematic approach to determine the sequence, between milestones or key phases, within the construction project. In all cases observed, the phase scheduling was completed for the entire construction process at a one-day workshop. Still, because the sequence was determined early in the construction process, the reliability was low. The unpredictable nature of the construction processes has in all cases enforced several changes of the sequence throughout the project.

In the Phase scheduling process it was found that the Critical Path Method and slack analysis had no attention. This could have served as guidance to secure a realistic and not too tight sequence. Conflicts caused by a too tight schedule have been observed at all four cases. The effects of a too tight schedule were mainly inflexibility towards changes. In construction, changes occur on a daily basis. Limited slack between activities was making the schedule unable to absorb variation in production rates. Thus, a tight time schedule does increase the number of hot spots causing delays and conflicts to be easily transferred between contractors and leading to a more chaotic, complex and uncontrolled construction site. Conflicts have been observed when attempting to interrupt the workflow and to completely obstruct the subsequent subcontractor in working efficiently.

During the Phase scheduling the detail level has in all cases been increased. This decreases the overview and transparency in relation to the Master Schedule. Still at this level only duration and interrelationships between activities have been of interest. Thus, none of the cases did at this stage shown interest in flows, by for instance seeking to secure a constant workflow or high utilization of machinery. One important element in the Phase scheduling process was the communication and collaboration between contractors and site management which increased the quality of the schedule. Furthermore, involvement increased awareness to interrelations which often helped the contractors to avoid or at least to predict future conflicts.

Look-ahead planning

Look-ahead planning was applied as a tool to ensure that only sound activities entered the Weekly Work Plans. Sound activities have been ensured by applying the making ready process where the necessary preconditions were fulfilled. At all four sites, and in accordance with LPS theory, the seven preconditions were applied as a checklist.

Sound activities were moved to a buffer, hereafter they were, when needed, selected to the Weekly Work Plans. During the case observations it was found that the fulfillment of the seven preconditions had a tendency to change over time, i.e. an activity that has been judged sound could easily later become unsound. To avoid that unsound activities are moved from the buffer into the Weekly Work Plans an additional weekly health check of all buffered activities should be implemented. The health check will discover problems proactively while there still is time enough to make small adjustments in the schedule. Changes in soundness is experienced to occur unexpected, therefore the weekly health check should A) be supplemented by a soundness awareness and B) supported by a action plan of how to handle unsound activities in the work flow.

In all cases the buffer level was kept between one and two weeks. The buffer has throughout the study proven critical to avoid the effect from congestions in the Look-ahead process and thereby to continuously feed the Weekly Work Plans. On site every trade was dependable of tasks that actually could be conducted. When the making-ready process progressed too slowly the capacity of the workforce was starting to exceed the amount of work ready for conduction resulting in unutilized workforce and delays. To avoid this and to handle congestions in the making ready process the production can be simplified by reducing both tasks and trades at the construction site and by supplementing the existing buffer with flexible buffer activities and slack between activities on the critical path. Flexible activities are not tied to the schedule, but can be moved within sequence-defined boundaries (Echeverry *et al.* 1991). Thus, flexible activities do enable adjustments within the sequence, which makes buffering less complex.

The Look-ahead Schedule has in all cases been implemented as a systematic approach to increase schedule reliability. Inflow variation has been reduced by securing that sound activities were matched to capacity. Simultaneously, a workable backlog has been maintained serving as a buffer against unexpected constraints in the Weekly Work Plans. Despite of the importance of ready work activities, the responsibility for ensuring progression has in all cases been placed at the individual subcontractor. However, weekly meetings have been arranged between the subcontractors and the site-manager. The weekly meetings were implemented to allow the site-manager to help, support, and follow the process.

The making ready process has successfully increased the number of sound work activities in the schedule (Ballard 1999). When making activities ready for conduction, it is important to stress that it is not enough to only ensure that activities can start on time but also finish on time. In all four cases it has been observed that the fulfillment of constraints was proceeding without regarding the quality of the fulfillment. From the observations it can be concluded that in order to improve productivity on the construction site the making-ready process must seek towards optimal conditions. Not only securing that workers are present, but also focusing on getting the most skilled crew to complete the task. Not only ensuring that enough space is present, but securing optimal working conditions. Not only securing that machinery and equipment is present, but secure the right and most suited equipment is present, etc. Two basic parameters have been observed as important when securing optimal conditions: the presents and the quality of the fulfillment. If optimal conditions are achieved the productivity and likelihood of error within the process will decrease which leads to an increased PPC level. It is important to stress that variations in preconditions still can interrupted the process.

Even though the Look-ahead Plan has been applied to secure the reliability of the Weekly Work Plans nothing was done to improve the schedule itself. The flow of workers, material, machinery, space etc. has neither been followed nor regulated in the schedule. Therefore, without putting the brains on, the making ready process ends up being a monotone and thoughtless process.

Weekly Work Plans

The lowest level of planning in LPS is the Weekly Work Plans. All cases applied this. The result of the Weekly Work Plans has, besides the "final" schedule, been commitments to the next week's work. To measure the quality of the schedule a PPC calculation was carried out. Both the scheduling of the weekly activities and the follow-up process including the PPC calculation has been taken place at a weekly basis, but only in half of the

cases (case 2 and case 4) last week's progress has been examined including calculation of the PPC measurement. This process should ideologically take place as the site-manager and subcontractors walk around the construction site, but in all cases the follow-up process has been completed from a nearby meeting room. After the PPC calculation was completed, next week's activities have been determined. As a part of the scheduling process the sequence and construction flow has been discussed at these meetings. These discussions often revealed unidentified interrelationships. Even though communication and collaboration are important the amount and duration of the meetings need to be limited to avoid long sessions with inactivity. It has been observed that in long scheduling sessions the concentration-level had a strong tendency to decrease resulting in slow progress and low quality commitments.

The quality of the commitments has in all cases been of crucial importance. A good schedule should be robust, reliable and trustworthy, and most importantly consist of binding commitments from all project participants. At situations where the schedule continually was rethought and changed, the schedule lost credibility. Moreover, changes have been observed to cause confusion which has been leading to misunderstandings and in extreme situation it changed how the schedule was perceived. Too many changes had changed the subcontractors' interpretation of the commitments from binding to only guiding.

When applying LPS the only focus has been on obeying the schedule and improving the schedule itself to ensure schedule reliability. Thus, scheduling via LPS had no focus on either the cost or the quality of the outcome. From the observations it can be concluded that quality control was necessary to ensure that activities were rightfully completed. Therefore, quality needs to be considered to achieve a correct impression of the progression within the construction process. Hence, poor quality and the related defects have to be deducted from the performance. Quality can be ensured by controlling, which for instance could be undertaken by either the site-manager or the subsequent crews. Actually quality control is too late because it is not stopping the problem; ideologically quality needs to be ensured.

Non-completions are a fact in today's construction and were observed multiple times in all cases. A main cause for non-completions was, in all cases, changes in soundness of the activity. The observed changes were originating from a changing soundness in ready work or from changes in the basic assumptions in the schedule. According to LPS theory, non-completions should be followed by a root cause analysis to investigate the triggers and to avoid repetitions. In all cases only minimal effort to do so was observed. Understanding the triggers is important and can help the site-managers to predict future changes. Furthermore, to avoid misunderstandings changes should be handled through communication and collaboration between the project participants. In all cases nothing was done to foster and support the communication and collaboration onsite, (i.e. outside the boundaries of the scheduling meetings), which therefore all too often failed.

General comments

A general tendency to ignore flow, critical path, and slack considerations in the scheduling process has been observed. In LPS theory sequencing is only based on interrelationships and durations. Moreover, LPS does not consider the interplay between the schedule and the surrounding world, i.e. a closed system model. Changes outside the schedule itself were in relation to Leavitt's Diamond affecting the schedule. For instance, it could be beneficial for the client to make a "lifecycle" plan considering expected usage within the buildings lifetime. These considerations could then be incorporated in the building's design. By forcing the client to carefully consider the building's usage inappropriateness in design can be caught before execution and possibly limit design changes which change the foundation to the schedules. Thus, the result will be a more reliable and thought through construction project which is easier to schedule.

Finally, the atmosphere wherein the scheduling process proceeds was important to the comfort of the individual participant and should be supported by leadership. In LPS theory, as well as on the four sites followed, there was limited interest in the soft values of such a managerial approach. In all cases, it should have been a crucial management task to ensure comfort because it is the breeding ground for motivation and mutual trust. The motivation of employees had significant impact on the output both regarding quality and quantity.

Discussion

The research of LPS has shown several gaps in the current LPS scheduling methodology which makes improvement possible. Figure 1 illustrates pros and cons in relation to each level of the LPS methodology. Connections between the schedules are also shown.

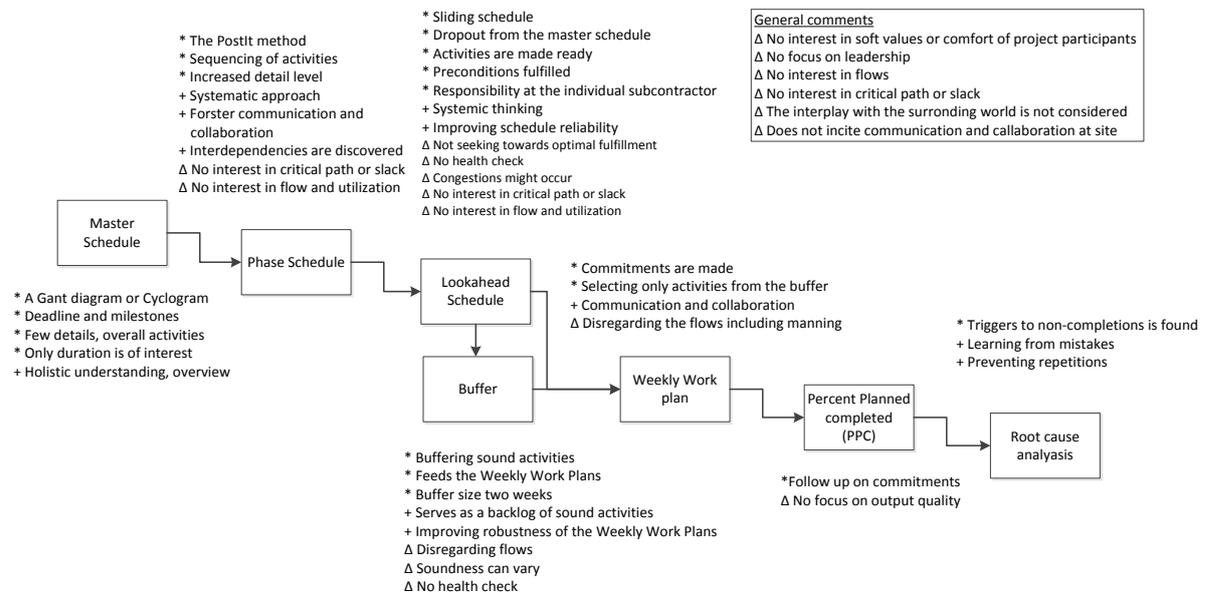


Figure 1: Pros and cons to LPS. (*) marks the subprocesses at the scheduling level, while (+) marks the positive effect and (Δ) marks the downsides or limits in the existing system.

As shown in Figure 1, the research has revealed a number of both pros and cons to the LPS methodology. Several of the revealed pros are related to the selection of activities to the schedule. Today the sequence is mainly grounded on interrelationships and durations of and between activities. To help optimize the sequence the existing selection criteria should be supplemented with flow and slack considerations. These parameters should be included already at the Phase Scheduling level. In the sequencing process variation in flows, such as manning, should be minimized.

Uneven production flows at the construction site are undesirable, because it creates variation in productivity and induces a risk of unutilized “flows”, like for instance manning. Furthermore, an uneven flow does affect the efficiency of buffering sound activities. Thus it will be much easier to buffer against variation with even flows. In a workweek containing several activities the buffer should contain several buffer activities. While the buffer, in a workweek with few activities only should contain very few activities. Since the buffered activities are normally next week’s work, the buffer should at least be supplemented with flexible activities.

Slack considerations are important in order to increase the robustness of the schedule. Especially slack between activities on the critical path has to be considered. Since slack on the critical path is expensive and postponing the end deadline it is important that the incorporated slack is adequate and fits the uncertainty in the process. If no slack is applied on the critical path variations cannot be absorbed and will therefore cause delays. To avoid daily penalties the work has to be accelerated which is costly (Thomas 2000).

If the determined sequence in the Phase Schedule is including flow and slack considerations these considerations are passed on into the Look-ahead schedule. A constant in- and outbound flow in the Look-ahead plan removes critical situations with many activities to make ready. This makes it easier to observe the making ready process

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and feed the Weekly Work Plans. The buffering process is made more effective where one week buffer is actually corresponding to one week's work. Finally, on site, the flow and manning are stabilized. Furthermore, the constant flows do make it easier for all project participants to allocate company resources. If the manning is kept stable the risk of conflicts transmitted from site to site is reduced (Bertelsen and Koskela 2004).

Because changes and variation are facts in onsite construction flows, slack and the critical path need continuously to be monitored. By following these parameters conflicts can be identified before evolving. Small adjustments in the schedules can be used to absorb the conflicts while still keeping a reasonable constant flow and manning.

A critical con in LPS is that scheduling is treated as a mechanical mechanism. Theoretically, there is an absence of management considerations in relation to leadership and the individual's comfort. Comfort is the breeding ground for motivation and mutual trust. Furthermore, increased comfort will increase the schedule reliability because accountability and dedication among the project participants increase (Lindhard and Wandahl 2012a). Therefore, soft values should be fostered by management and should be supported by the leadership onsite.

The analysis did furthermore reveal a number of cons. The remaining cons are treated in the result section at the relevant schedule. Therefore, the key cons are just listed underneath:

- Nothing is done to prevent or handle congestions in the making ready process.
- The soundness of ready work can vary, but nothing is done to secure that the buffered activities are ready when moved to the Weekly Work Plan.
- Output quality of completed tasks is not considered.
- The interplay with the surrounding work is ignored.
- No initiatives incite to communication or collaboration at site.

In future research more specific selection criteria will be determined and a practical and direct usable approach to determine the schedule which handles flows and slack will be developed. Future research might also include simulations to document the effect of the changes in the scheduling system.

Conclusion

LPS was analyzed in an attempt to develop scheduling at onsite construction. The research is based on four case studies which are combined with theory. The research revealed several weaknesses in the existing system. Eliminating the weaknesses by rectifying and making small changes will increase the quality of the schedule. The paramount critic point, found during the analysis, was that the sequence only was based on interdependencies between and duration of activities. In this process, flows and slack also needs to be considered. Deliberate involvement of flows and slack will lead to reduced variation and secure increase utilization rates on site.

LPS's mechanical scheduling process needs to be carried out with focus on the comfort of the individual craftsman. Management and leadership need to foster and support soft values. Increasing comfort will lead to improved schedule reliability, and increased onsite productivity because motivation, accountability and dedication among the project participants will increase.

Congestions in the making ready process can occur. This is critical because the making-ready process constantly needs to feed the Weekly Work Plans. A constant flow will reduce the risk of congestions because situations

where a lot of activities suddenly need to be squeezed through the process are avoided. Additionally, to prevent congestions minimizing tasks and trades at site and using flexible buffer activities are suggested.

Furthermore, LPS does not consider the risk that the soundness of buffered activities changes. To minimize the risk of moving an unsound work task from the buffer to the Weekly Work Plans a weekly health check is proposed. Finally, LPS is only measuring the quality of the schedule and not the quality of the work. The output quality should be included in a measurement to monitor and achieve a correct impression of the progression at the construction project.

In general construction is dominated by poor scheduling. Poor scheduling has a negative effect on the performance onsite, which results in a mediocre workflow, a mediocre productivity, and delay. Therefore, to utilize the capabilities in the production system, onsite scheduling needs to be improved. In this research scheduling has been sought to be improved by analyzing LPS. Pros and cons has been identified and discussed in the search of improvement.

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On the Road to Improved Scheduling: Reducing the Effects of variation in Duration

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ABSTRACT

Scheduling in onsite construction is based on commitments. Not kept commitments are resulting in non-completions which lead to waste. Moreover, it is important that commitments are made realistic to avoid both positive and negative variation in duration. Negative variation is destructive to plans and schedules, and is resulting in delays; while positive variation is destructive to productivity by creating unexploited gap between activities and thus inducing unexploited capacity. By registering non-completion at three construction sites, the magnitude of activities inducing negative variation has been mapped. In total 5424 activities has been registered whereof 1450 activities ended up as non-completions; thus, did 27 % of the scheduled activities not finish on scheduled. Both positive and negative variation can be minimized by improving the quality of the commitments. Moreover, positive variation can be exploited by A) ensuring that the crew finishing an activity to early can continue their work and B) ensuring that any connecting activity can start as fast as possible.

Key words: Variation, Scheduling, Waste, Construction management

INTRODUCTION

Production control is an essential part of every construction project and it is a necessity in the attempt to be able to handle the complexity of the project. In construction, production is characterized by being on-site and fixed position manufacturing, unique designs and one-of-a-kind production. Moreover, the projects are completed by a temporary organization of competing contractors which have to complete highly interrelated, interacting, and overlapping activities with limited space, multiple components, and a lack of standardization (Salem *et al.* 2006; Bertelsen 2003a; Ballard 1998; Schmenner 1993). In this complex, dynamic, and

uncertain context the schedule is trying to create order by adding structure to the process. It is a tool to keep track of the production so expenses in time and resources are kept under control. The objective of production control is thus to identify problems or negative variations, after which corrective actions can be taken (Ballard 2000).

In the Last Planner System (LPS) control is divided into three main tasks: planning, scheduling, and monitoring (Ballard 2000). The planning specifies what to be conducted and in which sequence. Scheduling determines the actual timing and duration of activities, while monitoring to keep track on the production provides feedback. Feedback is provided by comparing the actual progress with the conducted plans.

In LPS control is handled through four main schedules and a follow-up process (Cho and Ballard 2011; Salem *et al.* 2005). 1) The Master schedule, which cover the entire construction process and establishes overview by including important milestones. 2) The Phase schedule which, optimize the sequence of the construction project. 3) The Look-ahead plan, which contains a making ready process. In the making ready process the preconditions for production of upcoming activities are fulfilled. 4) The Weekly Work plan, which is a one week plan containing the activities which in the following week will be conducted. The plan is based on mutual commitments between the subcontractors. Ensuring that only ready activities enters the Weekly Work plans increases the success rate of completed tasks and increasing the reliability of the schedules (Ballard and Howell 1995). The four schedules are followed by a follow-up process, where the quality of the schedule is measured through the Percent Planned Completed (PPC) measurement. If low PPC is measured root causes are investigated and eliminated in order to increase productivity (Ballard 1994; Howell and Ballard 1994). This way, the PPC measurement serves both as a feedback system and as a learning system.

METHODS

Three construction sites are followed to observe and register causes for non-completed activities. Collection of qualitative data made it possible to get an apprehension to extend but also the causes to non-completion in onsite construction.

To ensure high quality of the collected data, the cases were selected based on three basic requirements: Last Planner Systems had to be applied, and PPC calculation had to be conducted. Furthermore, since most data are collected from archives, reasons for non-completion or non sound activities had to be described. To secure consistency in how the registration is carried out all three construction projects followed have the same site manager in charge. In the selection process, mail correspondences and phone conversations with site managers and company

consultants secured the fulfillment of the mentioned requirements.

Collection of data is carried out through either the LPS meetings or archived summaries from the LPS meetings. The LPS meetings are at focus because the PPC calculation and collection of reasons for non-completion take place at the LPS meetings. Furthermore, the LPS meetings includes the Look-ahead planning and the scheduling of the next weeks plans which in relation to LPS-theory are completed in collaboration between site-mangers and foremen. The use of archives enables collection of data from the entire construction period.

The archived data are supplemented with onsite observations to get an insight to how the meeting actually proceeded and how non-completions were recorded. Besides participating in the meetings the cases studies were supplemented with on-site observations and semi and unstructured interviews. These supplementing studies were carried out to increase the insight to how non-completions were handled and registered on-site. Even though these supplementing methods only were applied at one of the three construction cases the results were generalized. The generalization is based on the fact that all construction cases had the same site-manger in charge.

The data analysis started by categorizing the recorded causes to non-completions into main categories. This is done to get an overview to causes to non-completion and to simplify the problem. Data collection from the cases is listed in **Error! Reference source not found..**

Table 1: Data collection from the three case studies

	Case 1	Case 2	Case 3
Contract form	Turnkey contractor	Turnkey contractor	General contractor
Project followed	Entire construction period	23 weeks	Entire construction period
From archives	Reports from LPS meetings	Reports from LPS meetings	Reports from LPS meetings
Construction period	65 weeks	23 weeks	60 weeks
Activites registered	2239 activities	593 activities	2592 activities
Non-competions	746 activities	134 activities	570 activities

RESULTS

In total 5424 activities has been registered whereof 1450 activities ended up as non-completions. This entail that the average PPC for all construction projects is

73,27 %. Thus, is the likelihood of completing two connected activities without delay only (73,27²) 53,68 %. Moreover, the likelihood of, without delay completing every activity in a construction project including only 100 activities is approximately zero. Thus, external elements such as slack and management adjustments are necessary to avoid accumulated delay between interrelated activities.

At the three construction projects the cause to every non-completion has been registered. The results are presented in Table 2. The causes to non-completions has besides an “unknown” category, been divided into 11 categories. Nine categories are non-completions caused by not-ready activities which cannot be completed. Six of these categories are corresponding to the preconditions presented by Koskela (1999), while the last three categories are an expansion of Koskela’s (1999) external conditions. This expansion is presented in Lindhard and Wandahl (2012b) and includes the categories: Weather conditions, unexpected conditions, and safety. The remaining two categories are containing non-completions caused by changes made in the schedule or activities where rework is required.

The “unknown” category contains non-completions where the reasons have not been identified. It contains, among others, non-completions where the completion duration exceeded the scheduled. The remaining registrations, if any, could be caused by A) the “unknown” category can be caused by not identified categories or sources to non-completions. B) The “unknown” category could be non-completions related to a single or few categories were the registrations have not been correct completed. C) The unknown category is common mistakes in the registration process, and should be equally distributed between all the identified categories. D) Finally, the “unknown” category could be caused by a combination A), B) and C).

Table 2: Deviation of non-completions

	Registration of occurrences	Registrations pr. 100 planned activities
Unknown	612	11,28
Connecting works	250	4,60
Change in work plans	147	2,71
Work force	134	2,47
Weather conditions	92	1,70
Materials	87	1,60
Construction design	76	1,40
Space	21	0,39
Equipment	13	0,24
Rework	8	0,15
Unexpected conditions	6	0,11
Safety	4	0,07
Total	1450	26,7

From Table 2 it can be concluded that approximately 27 % of all activities is delayed due to negative variation in the execution process. From this follows that the remaining 73 % of the activities theoretically will be completed on time or before scheduled. Assuming that the duration of an activity is normally distributed then the negative variation should in theory be more than counterbalanced with the positive variation of subsequent activities.

DISCUSSION

Scheduling is based on commitments. Non-completions are activities not completed according to schedule, and thus not kept commitments made at the weekly LPS meetings. Therefore, in order to improve onsite scheduling the number of non-completed activities must be minimized. This increases the schedules robustness and reduces the risk of delay.

In construction both positive and negative variation is undesirable (Lindhard and Wandahl 2012d). Negative variation is destructive to plans and schedules, and is resulting in delays (Howell and Ballard 1994). This was clear illustrated in the Parade of Trades simulation by Tommelein et al. (1999). Most often the positive variation does only create unexploited gap between activities. The wasted gaps are an effect of multiple trades completing highly interdependent activities (Bertelsen and Koskela 2004; Bertelsen 2003b). Interdependencies between the multiple trades on site make it difficult to adjust the sequence because the next trade is often occupied elsewhere, not-aware of the gap, or simply not ready to start the conduction of the following activity. Moreover, onsite construction is dominated by long changeover times caused by the complexity and the fact that onsite production is not following a straight assembly line. In construction different trade's does simultaneous work at interacting and overlapping activities (Lindhard and Wandahl 2012d). This makes it difficult to keep a sense of perspective and complicates the management and communication at site.

The average PPC is way below the theoretical 100 percentage level. One reason to the high number of non-completions is that non-sound activities are able to enter the Weekly Work Plans. Despite the making ready process at the Look-ahead level in LPS removes constraints, resurrections are still possible. To detect the resurrections Lindhard and Wandahl (2011) suggested to implement a health check just before an activity enters the weekly work plan.

When disregarding the "unknown" category, approximately 15 % of all activities entering the Weekly Work Plans end up as non-completions due to problems with at least one of the 9 mentioned preconditions. The remaining 2-3 percentage is caused by rework and changes in work plans. Though, the triggers to changes in work plans, besides just bad scheduling, can be related to delay,

non-sound work activities, or to rework.

There seems to be two roads to achieve increased robustness in the schedule. A) Exploiting the positive variation in an attempt to counterbalance the effect of non-completions including negative variation. B) Minimizing the number of non-completions to raise the PPC level above the 70 percentage level.

Exploiting positive variation

The positive variation is exploited if the utilization of the capabilities in the production system is kept high. This includes high utilization of the present work force, equipment and machinery, and space etc. It is important to notice that even though lowering the manning will result in high utilization of the remaining work force the capabilities in the production system is not exploited.

Thus, the first step is to ensure that the crew finishing an activity to early can continue their work while the second step is to ensure that any connecting activities are able to start as fast as possible. One approach to fulfill the two steps would be by buffering activities or workforce, respectively. Because of the associated cost buffering is not the ideal solution to handle variation and should therefore be minimized (Ballard and Howell 1995; Howell and Ballard 1994). Of course the need for buffering will decrease as variation an uncertainty is removed from the schedule (Ballard 1999).

The needs of buffering will decrease if the complexity of the construction process is reduced. This can be achieved by reducing the number of activities and trades on site (Lindhard and Wandahl 2012c). Moving activities away from the construction site could be achieved by increased prefabrication, preassembly and modularization. Fewer activities and fewer trades equal less interactions and interdependencies between the present trades (Lindhard and Wandahl 2012c). Moreover, modularization will ideologically simplify the assembly process at site leading to less complex work activities. If task complexity is reduced the need of a specialized work force is reduced. Thus, the remaining activities could be completed by more general skilled craftsmen. This increase the flexibility and adaptability in the assembly process (Lindhard and Wandahl 2012c). Furthermore, general skilled craftsmen will be capable of completing the same buffered activity reducing both buffer size and the related waste.

Minimizing the number of non-completions

To raise the PPC level non-ready work activities should be prevented from occurring in the Weekly Work Plans. Thus, the quality of the making ready process

should be improved. Non-ready activities emerge in the Weekly Work Plans because of the varying nature of the preconditions (Lindhard and Wandahl 2011). If possible the ideal solution would be to avoid or at least reduce the variation in the individual precondition. By finding the root cause to variation and prevent that from reoccurring variation in the preconditions can be avoided. Thus, non-ready activities will not occur in the Weekly Work Plans.

It will be impossible to stop all variation in the preconditions. Unexpected and undiscovered changes can evolve affecting the soundness of an activity. Since soundness cannot be guaranteed Lindhard and Wandahl (2013b; 2011) suggest a weekly health check of all buffered activities to prevent non-sound activities from entering the Weekly Work Plans. Moreover, Lindhard and Wandahl (2013b) also suggests to briefly checking up on the soundness of the scheduled activities at a daily basis. The daily health check will help in detecting conflicts earlier while the still is time enough to make small adjustments in the schedule and thus avoiding interruptions in the workflow.

Reducing the risk of varying preconditions and avoiding non-ready activities from entering the Weekly Work Plans will increase the quality of the making ready process. By not only trying to fulfilling the basic requirements in the preconditions, but attempting to secure optimal production conditions, productivity will increase because the risk of negative variation is reduced (Lindhard and Wandahl 2013a).

Not all changes can be stopped by improving the making ready process itself. For instance does changes in the construction design emerge outside the construction site and therefore without control from site management. In an attempt to improve the design procedures, to design not only for present but also future needs Lindhard and Wandahl (2012a) suggested that the owner should complete a “*lifecycle*” plan of the expected usage in the buildings lifetime. By designing for the future, fewer changes are expected to occur within the construction process itself. Naturally, everything cannot be planned on beforehand. Therefore, is it also expected that unforeseen work activities emerge as the projects proceeds. The earlier these activities are discovered the more time is there to handle and avoid interruptions in the scheduled work flow.

The presence of labor is important in construction because every activity needs labor to be completed. Moreover, the output quality is depending of the labors performance. Therefore, the skill and motivation is in particular important. While skill is a constant motivation is changeable and is affected by the surrounding working environment, supported by ethical values and leadership, it should ideally provide comfort and mutual trust (Lindhard and Wandahl 2012). Besides increased output quality increased motivation will lead to increased accountability and productivity (Singh 1996; Olomolaiye 1988). Accountability raises the likelihood of observing the commitments within the schedule and thus increases the schedules robustness (Lindhard and Wandahl 2012).

CONCLUSION

Time overruns is an everyday experience in today's construction projects. By increasing the robustness of the schedule the risk of time overruns can be decreased. Two roads to increased schedule robustness were identified. A) Exploiting the positive variation in an attempt to counterbalance the effect of non-completions including negative variation. B) Reducing negative variation. This is achieved by minimizing the number of non-completions to raise the PPC level above the 70 percentage level.

Positive variation is exploited if the utilization of the capabilities in the production system is kept high. This is achieved by ensuring that a) that the crew finishing an activity to early can continue their work and b) that any connecting activities are able to start as fast as possible. Several initiatives exists i.e. simplification of the production which can be achieved by reducing the number of tasks and trades on-site.

Negative variation is reduced if activities are ensured to be "ready" at the time of execution. Too minimize the risk of non-ready activities in the Work Plans; it is proposed to implement a weekly health check together with daily health updates and a soundness awareness among all project participants. Moreover, repeating non-completions can be avoided by detecting root causes and eliminating them. Avoiding repetitions is a part of LPS's learning process.

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Looking for Improvement in Last Planner System: Defining Selection Criteria

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ABSTRACT

Last Planner System has been critiqued for an inconsistent application of flows. Central for this critique was that the sequence of activities was determined based on only duration and interrelationships. In an attempt to improve the on-site scheduling processes, an in-depth analysis of selection criteria was carried out. Six flows are identified as relevant: workforce, material, and machinery which comprise the needed resources and safety, climate conditions, and space which affect the pace of the work. Because of the importance to progress in the workflow, and the on schedule completeness of activities, all six flows need to be systematically controlled. The output of the analysis is a list of recommendations of how to refine the schedules by including the six flows both in the Phase Scheduling, the Look-ahead, and the Commitment level.

Key words: Construction management, Flow, Last Planner System, Scheduling, Sequencing

INTRODUCTION

In Last Planner System (LPS) focus is on making the schedule as reliable as possible (Ballard 2000; Ballard and Howell 1995). According to LPS theory, increased schedule reliability does lead to increased on-site productivity (Ballard and Howell 1995; Ballard and Howell 1994). Schedule reliability is measured in the percentage planned completed (PPC) measurement; which is said to be a quality measurement of the schedule (Ballard and Howell 1994; Ballard 1994). In this research, the focus is moved from schedule reliability onto sequence quality. This is done in an attempt to make the sequence as ideal as possible to improve the work flow and processes at site and through that increase on-site productivity.

LPS consist of four schedules: 1) The Master Schedule, containing milestones and deadlines, 2) the Phase Schedule, including the sequencing processes, 3) the Look-ahead Schedule, where activities are made ready for conduction, and finally, 4) the Weekly Work Plans which contains the actual commitments to what is carried out

on-site (Ballard 2000).

A basic part of Lean Construction is the Transformation – Flow – Value (TFV) theory, which was introduced by Koskela (Koskela 2000; Koskela 1992). Transformation is referring to the transformation of input to output, flow is referring to the flow of work, and value is referring to the creation of value through fulfillment of customer value. In LPS the flow considerations are only adopted at the Look-ahead level where activities are made ready for conduction. In the making ready process, the seven flows of construction are applied to ensure that every constraint is removed. The seven flows were introduced by Koskela (1999) as the preconditions which have to be fulfilled to ensure that an activity can be conducted. The seven categories of preconditions are:

1. Construction design; correct plans, draft and specifications are present
2. Components and materials are present
3. Workers are present
4. Equipment and machinery are present
5. Sufficient space so that the activity can be executed
6. Connecting works, previous activities must be completed
7. External conditions must be in order

In a research study conducted by Lindhard and Wandahl (2012a) the preconditions to work task were examined. As an output from the research it was proposed to expand the construction design category to include external laws, authorizations, and agreements together with management decisions such as communication, coordination, and collaboration issues. Moreover, it was proposed to split the “external conditions” category into three categories. Currently the “external conditions” category covers several fundamentally different subcategories. The “external conditions” category was divided into the following:

- 7a. Climate conditions must be acceptable. The precondition focuses on the effects from the external environment such as: rain, snow, wind, heat, cold etc.
- 7b. Safe working conditions must be present. The national “Health and Safety at Work Act” has to be obeyed to keep the employees safe.
- 7c. The surrounding conditions must be known. The precondition focuses on securing that existing conditions, if necessary, are examined. Problems often arise during excavations or refurbishment assignments.

In order to improve LPS, and since it is based on lean considerations, flow considerations should be included in the three schedules conducted at site, i.e. the Phase Schedule, the Look-ahead Schedule, and the Weekly Work Plan (Lindhard and Wandahl 2013a). A way to incorporate flow conditions into the schedules is, when conducting the schedules, to include flows in the selection criteria. In LPS only

duration and interrelations between handoffs are considered. The criteria to the selection of activities are important because it is decisive to the “design” of the schedule. By expanding the selection criteria, sequence quality is improved.

This paper is based on the outcome from the findings in Lindhard and Wandahl (2013a) which through case studies analyzed pros and cons to LPS and found that the current criteria for selecting activities to the schedules needed to be expanded with both flow and CPM consideration. The aim of the paper is to establish a set of recommendations of how flow considerations can be included when selecting activities.

METHODS

Four cases comprise the foundation for the presented research. The study took its outset in Eisenhardt’s (1989) case study guidelines. Four cases were selected to ensure a “*theoretical saturation*” of collected data cf. Eisenhardt (1989), and because it enables triangulation of data sources which increases the trustworthiness of the data (Krefting 1991). Triangulation of the data sources revealed a consensus between all the four cases.

The case studies had an exploratory approach (Tellis 1997; Yin 1993) where the nine preconditions were observed in their context. By studying the preconditions in their context the collected data has an increased richness and depth (Ulin *et al.* 2004). Thus, by observing how production progresses on-site and how the individual predefinition affects and is affected a lot is learned. Based on the observations, the relevance and the implication of each preconditions is revealed. Moreover, by observing elements influencing the preconditions an insight of how to manage the precondition is gained. The knowledge gained throughout the case studies is creating the input in the analysis and hence forming the basis for the final recommendations.

Key data to the four cases studied can together with details to the data collection be viewed in Table 1.

Table 1: Data collection from the four case studies

	Case 1	Case 2	Case 3	Case 4
Type	Renovation	Construction	Construction	Renovation
Details	Public housing	Educational institution	Nursing home	Hospital
Contract form	Turnkey contractor	Turnkey contractor	Prime contractor	General contractor
Contract period	26 month	16 month	17 month	7 month

Contract value	\$4.5 million	\$29.1 million	\$3.9 million	\$5.5 million
Site observations	Once every fortnight in total 5 observations.	1-2 times every fortnight in total 8 observations.	1-3 times every fortnight in total 8 observations	1 time every week in total 6 observations
Observation length	10 weeks	10 weeks	10 weeks	6 weeks

ANALYSIS

In a research, conducted by Lindhard and Wandahl (2013a) the selection criteria's within the LPS was critiqued. The critiqued was founded on the fact that LPS only includes duration and handoffs when determining both the overall sequence and the actual work plans. Moreover, Lindhard and Wandahl (2013a) found an inconsistent application of flows in the scheduling process. Today, flows are only considered at the Look-ahead level where they serve as preconditions to ensure that activities are made ready for conduction. As mentioned in the introduction section flow considerations are a central part of Lean Construction and the TFV theory. Thus, to improve the selection criteria flow considerations should be included. This can be achieved by incorporating the preconditions into the selection process.

The following contains an in-depth analysis of selection criteria's. This analysis takes its outset in the above mentioned preconditions of construction, in an attempt to improve the on-site scheduling processes. As mentioned in the introduction section the preconditions to work tasks in construction can be divided into nine key categories. This includes: Construction design, materials, workers, equipment, space, connecting works, climate conditions, safety, known surroundings. All mentioned preconditions have to be fulfilled before an activity can start which is why the preconditions in LPS is used to secure that only sound work enters the Weekly Work Plans.

Not all preconditions are important during the completion phase. The "known surroundings", "construction design" and "connecting works" categories are in general only important to ensure that an activity can start. Only in very rare exceptions, changes in soundness will occur in the three categories. Changes in the "connecting work" category affect the soundness of the activities while changes in the "known surroundings" and construction design" category effects the basics which defines the work task, and change the work task itself. In all cases the result is an interruption in the progressing work which leads to decreased productivity.

The known surroundings category provides information to the design process and to determine necessary precautions during execution. When an activity starts all

relevant information should already have been collected from the surroundings. Thus, no inputs are expected from the “known surroundings” category when an activity is being “processed”. Even so, not all relevant information from the site is necessarily discovered in the preliminary examinations. Therefore, unexpected discoveries are still able to occur during the execution phase.

Before an activity can start, the construction design has to be decided; this includes relevant drawings and task specifications. Often the construction design changes during the construction face; therefore, it is important to continuously update drawings and specifications to avoid misunderstandings and the possibility to proceed with incorrect plans. Even though design changes are normal in construction project; the risk of design changes in a work task during completion is very minimal.

Likewise “known surroundings” and the “construction design” categories, the completion of connected and interrelated activities is essential in relation to the soundness of the activities in the present Weekly Work Plans. The completions stage of previous activities is especially important between handoffs. Handoffs are important because work is changing hands between the different trades or subcontractors represented on site. Thus, handoffs are important to hinder interruptions in the workflow and to avoid unnecessary waiting. The deadline signals when the handoff shall take place, to avoid interruptions and unnecessary waiting slack can be incorporated in the schedule; these slack considerations are of particularly importance at the critical path to avoid delays in the overall construction process. In rare situations the completeness of previous activity can vary which result in rework, but normally the completion of previous activities has importance only in the handoff between the present and the succeeding trade.

The remaining six preconditions are all important both before and during execution. Three of them, including: qualified workforce, the needed material, the relevant equipment and machinery, are the resources which needs to be present during the execution phase to ensure the completeness of an activity on schedule. The remaining three including safety, climate conditions, and space have to be present to ensure that the process can proceed and affects the pace of the work. In extreme situations safety issues, climate hazards, and lacking space are all able to completely stop all progress at the construction site. Because of the importance to progress in the workflow, and the on schedule completeness of activities, all six preconditions need to be systematically controlled.

The safety of the workforce is important both before and during the execution. Therefore, necessary precautions have to be taken to ensure the safety of the workforce and to obey the national “Health and Safety at Work Act”. Before an activity can start the process has to be thought through and safety has to be ensured; during execution all involved should be aware of safety issues and act if detected to hinder accidents in developing. The safety “awareness” could be combined with other preventive precautions such as safety inspections, safety trainings, hazards

planning, alcohol screening etc. (Howell *et al.* 2002). Despite the effort, safety issues and hazards cannot be completely avoided. Often hazards develop as a chain of unforeseen events (Howell *et al.* 2002); this happens at a pace where they are difficult to detect and avoid. The risk for hazards increases as the workload increases; thus, is a company's eager to increase productivity pushing workers to work close to the boundary of safe working conditions (Howell *et al.* 2002).

Every construction project is surrounded by an external climate. The external climate does by a number of parameters such as temperature, wind, moisture, rain, snow, waves, and visibility (Lindhard and Wandahl 2012a) influence the work conducted at site. Since the climate itself cannot be changed the possible negative effect of the climate has to be handled to reduce or eliminate the effect. The quick changes in the climate impact makes it very difficult to plan for environmental issues; therefore, long term precautions, which has to be taken before problems can be forecasted, should be based on risk assessments. Some climate parameters changes with the season, for instance temperature; in such cases it is possible to wait and intervene only when necessary. When scheduling next week's work traditional weather forecasts can be used to adjust the schedule. Furthermore, short term precautions can be implemented to avoid the effects from the climate. In general many precautions to handling the surrounding climate has proven very cost full; therefore, price is often the primary parameter when comparing the cost with the benefits.

In construction a great number of work activities have to be completed simultaneously with only limited space available (Bertelsen 2003). The category space includes all elements which are needed to secure optimal working conditions to a specific work activity (Lindhard and Wandahl 2012a). Working conditions include working comfort, for instance temperature, lighting, noise, working postures, working procedures, working base etc. Moreover, working conditions does as mentioned include space issues, which include access to work place, mutual interruptions and delays caused by shared work areas, etc. To achieve ideal working conditions it is necessary to define good and bad working comfort. Afterwards, bad working comfort should be minimized while good working comfort should be maximized.

Construction is dependent on qualified labor. Thus manning is an essential resource which is needed to complete the work tasks on site. Both the basic skill and the motivation of the individual craftsman are important and affect both the pace of work and the quality of the output. Due to the relationships to output quantity and quality, the well being and personal comfort of the workforce is crucial important (Lindhard and Wandahl 2012). Aiming towards a steady manning, when scheduling activities, simplifies the buffering of activities, because one week's buffer then equals next week's work. The manning should only be adjusted as a last resort when a problem occurs on site. By lowering the manning the capacity is decreased and

production will slow down resulting in delay (Lindhard and Wandahl 2012b).

Material differs from the other resources needed in construction, because materials are depleted during the process. Because materials are depleted new materials continuously have to be delivered to the construction site. Moreover, every task needs its own special materials, resulting in thousands of different component which have to, in time, be delivered to the correct work task. The uniqueness of every work tasks creates complexity and increases the risk of non-present or incorrect materials. Furthermore, materials delivered to early have to be put on stock. Storing of materials has to be done carefully because of the risk of dwindling or damaged materials. Therefore, it continuously has to be ensured that the correct and fully functional materials are on site when needed. Finally, materials delivered just-in-time have an increased risk of not being present at the point of activity start. If the delay is occurring without a warning the delivery risk is combined with a shortened reaction time which makes it difficult to keep the production flow unaffected. In worst case the non-delivery is first discovered at the point of expected delivery. To ensure a constant feed of materials to the construction flow, the material flow has to be carefully thought through and include relevant logistics considerations and limitation. Moreover, the material flow has to be continuously monitored and controlled.

The last preconditions to a construction task are that the needed equipment and machinery are present. During execution phase the construction project is undergoing small sub-phases where different equipment and machinery is required. By compiling activities into small groups in relation to needed equipment and machinery, the gear does only have to be present in a restricted period. Restricting the presents of equipments and machinery by compiling of activities into groups, increase utilization rates and the necessity of sharing equipment and increase the interdependences between the crews on-site. To avoid conflicts and delay it is recommended to incorporate slack between handoffs. If slack is not incorporated the need for detailed plans and scheduled to control the process is increased. Normally breakdowns happen only rarely, but in harsh environment there is an increased tendency to experience breakdowns in the machinery. A breakdown has a major effect and on the work flow; therefore, it is necessary to minimize any downtime by either, maintaining, repairing, or replacing the machinery.

Recommendations at the Phase Scheduling level

At the initial scheduling level the main task is to create the network of activities. The basic parameters to define this network include duration and handoffs to identify interrelationships and draw the overall connections. The critical path should be calculated to gain insight to critical activities and if possible slack should be incorporated to minimize the risk of delay. To refine the network of activities the

six preconditions, which have importance during the execution process, are systematically linked to the schedule. This is done to identify and consider all critical elements in the schedule. Linking the six preconditions to the schedule supplements and enhances the existing management tools and increases the insight and understanding. The six preconditions include: safety, climate, space, workers, material, and machinery. The key points to go through are:

- Identify necessary safety precautions to the individual activity and plan for implementation.
- Identify critical climate parameters, consider possible precautions, and make a plan of action to different critical scenarios.
- Define the working area and space requirements to each activity. Ensure that space is available by linking usage to the schedule. Identify all elements which affect working comfort and seek to improve the conditions.
- Define the needed workforce to each activity and calculate the manning throughout the construction project. Aim towards a steady manning. Moreover, to improve output quantity and quality initiatives to secure comfort of the individual craftsman should be implemented.
- Define needed material to each work activity, and consider relevant logistic issues in relation to the material flow.
- Link shared material and equipment to each activity. Group the activities to improve the utilization rates. Create a back-up plan to minimize the effect of breakdowns.

Recommendations at the Look-ahead level

At the Look-ahead level the key purpose is to make activities ready for conduction. All nine preconditions have to be considered and fulfilled to ensure the soundness of every individual activity. Throughout the making-ready process it has to be ensured that all nine preconditions are fulfilled when the activity is scheduled to start. Activities with no constraints should be moved to a buffer but all preconditions have to be monitored to prevent resurrecting constraints. At risk activities should be kept in a “at risk buffer” until the risk is removed or the activity enters the Weekly Work Plan. At risk activities are activities which still contain constraints when entering the Weekly Work Plans (Liu and Ballard 2008). It is important to notice that the remaining constraints are expected to be removed before activity start, and could for instance be a late delivery of materials. Finally, the making ready process should seek towards optimal fulfillment of the preconditions to secure the best possible working conditions to improve the workflow and hinder negative variation which results in delay (Lindhard and Wandahl 2013b).

Recommendations at the Commitment level

Binding commitments are made at the point when an activity enters the Weekly Work Plan. To improve the quality and reliability of the commitments, they have to be reached in mutual agreement and with the best possible information in hand. First, the schedule has to be updated and reflect the current situation at the construction site. Based on the completion stage of the individual activity adjustments in the schedule has to be made to avoid any upcoming conflicts in handoffs. Second, the six preconditions which are linked to the schedule at the Phase Scheduling level need to be reincorporated to the schedule. This is achieved by systematically following the six preconditions and continuously update and integrate the results into the schedule. The key points to go through are:

- Consider the selected safety precautions to the individual activity, and follow up by site monitoring during the completion phase. Act immediately if anything critical is detected to hinder accidents in developing.
- Consider the implemented climate precautions and scenario plans and update if relevant. When scheduling next week's work, use weather forecast to keep track on the short-term effect of the climate parameters. Constantly follow the weather and act if critical changes occur.
- Update working areas and space requirements to each activity. Ensure that space is available by linking usage to the schedule. Consider the effect, of the initiatives implemented to improve the working comfort, and continuously seek for new ways to improve them.
- Make the final decision regarding the needed workforce to each activity and calculate next week's manning. Aim towards a steady manning throughout the entire construction project. Consider the effect of initiatives implemented, to improve the comfort of the individual craftsman, and continuously seek for new ways to improve them.
- Update needed material to each work activity and check for material availability. Consider site logistics and continuously seek for improvements.
- Update and link shared equipment and machinery to each activity to ensure availability. Group the activities, in relation to machinery usage, to improve utilization rates. Evaluate the maintenance and consider the effect of back-up plan in the search of improvements.

CONCLUSION

In an attempt to improve schedule quality, the criteria to the selection of activities to the schedule were examined. In a study conducted by Lindhard and Wandahl (2013a) it requested that today's criteria should be supplemented with flow considerations. Therefore, the nine flows were analyzed. Throughout the analysis it was found that only six of the flows were relevant as selection criteria. Of the six relevant flows three comprised the needed resources (workforce, material, and machinery) and three affecting the pace of the work (safety, climate conditions, and space). Because of the importance to progress in the workflow, and the on schedule completeness of activities, all six flows need to be systematically controlled. The output from the analysis is a list of tangible recommendations on how to include the flows as selection criteria both in the Phase Schedule, the Look-ahead Schedule, and the Weekly Work Plans.

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