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## **Scheduling of Large, Complex, and Constrained Construction Projects**

*An Exploration of LPS Application*

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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).

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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 Howell 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.

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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 11<sup>th</sup> of August 2011 and ended at the 21<sup>st</sup> 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

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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,

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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



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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.

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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).



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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).

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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%

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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%

Lindhard, S., Wandahl, S., 2014 "Scheduling of Large, Complex, and Constrained Construction projects – An Exploration of LPS Application", *International Journal of Project Organisation and Management*, vol. 6, no. 3, pp. 237-253. <https://doi.org/10.1504/IJPOM.2014.065258>

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-

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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.

Lindhard, S., Wandahl, S., 2014 "Scheduling of Large, Complex, and Constrained Construction projects – An Exploration of LPS Application", *International Journal of Project Organisation and Management*, vol. 6, no. 3, pp. 237-253. <https://doi.org/10.1504/IJPOM.2014.065258>

## 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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