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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

Biografical 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.

Søren Wandahl is Professor, M.Sc.ENG, Ph.D., at Aarhus School of Engineering, Aarhus University. Here he is a member of the Construction Management research group. Søren works with construction processes in research and teaching. Søren's research is primarily centered on value creation through e.g. strategic collaboration in the supply network, user involvement in the clients brief, and innovation of construction management processes in general. Søren's interest in engineering educations is also visible in his scientific contribution.

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

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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 stabile 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

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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 it 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 date from each case. Furthermore, the results later on show consensus.

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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.dk[1]. The association comprises 16 contractors applying Lean Construction, which represents a large proportion of 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 forthnight in total 5 observations.	1-2 times every forthnight in total 8 observations.	1-3 times every forthnight in total 8 observations
Meetings partispated 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 m^2. The main building was a three-storey building plus basement, in total 8000 m^2 and had an autonomous contract value on $21.75 million. The secondary building was a two-storey building with no basement, in total 3000 m^2. 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.

[1] Danish sister organization of Lean Construction Institute.

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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).

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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 competiveness in the surrounding marked (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

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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 constructions 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

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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.

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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. Fist 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.

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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

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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

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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 Wandhal 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 ads 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 misusage of LPS if implemented. A lack of guidance and support from

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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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