ON THE ROAD TO IMPROVED SCHEDULING – FITTING ACTIVITIES TO CAPACITY

Søren Lindhard[1] and Søren Wandahl[2]

[1] Department of Mecanical and Manufacturing Engeneering, Aalborg University, Fibigerstræde 16, 9220 Aalborg, Denmark

[2] School of Engineering, Aarhus University, Dalgas Avenue 2, 8000 Aarhus, Denmark

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.

[1] lindhard@m-tech.aau.dk
[2] swa@iha.dk

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 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 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

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, lowing 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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